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TMDL/303(d)
Redwood Creek TMDL

SUPPLEMENTAL REPORT

FOR THE

PROPOSED REDWOOD CREEK WATER QUALITY ATTAINMENT STRATEGY FOR SEDIMENT

Advocates for Redwood Creek- Alternative

PROPOSED CHANGES IN UPPER CASE LETTERS

prepared for

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North Coast Region
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SUPPLEMENTAL REPORT FOR THE PROPOSED REDWOOD CREEK WATER QUALITY ATTAINMENT STRATEGY FOR SEDIMENT

TABLE OF CONTENTS

INTRODUCTION

Redwood Creek watershed is a predominately forested watershed located north of Eureka in northwestern California. The purpose of the Redwood Creek Water Quality Attainment Strategy (WQAS) is to specify and explain the basis for a Total Maximum Daily Load (TMDL) and associated Implementation Plan provisions. The TMDL identifies total allowable loads and loading allocations that, when implemented, are expected to result in attainment of applicable water quality standards for sediment. The Implementation Plan specifies implementation actions needed to implement the TMDL and evaluate its effectiveness over time.

Protection of water quality will be achieved when the water quality objectives adopted to protect the beneficial uses of the Redwood Creek watershed and contained in the Water Quality Control Plan for the North Coast Region (Basin Plan) are met. The TMDL and Implementation Plan provide a framework for evaluating sediment problems in Redwood Creek watershed and taking actions to remedy these problems in a manner which will result in attainment of water quality standards.

TMDL Component

The TMDL section of the WQAS identifies total allowable loads and associated loading allocations that, when implemented, are expected to result in the attainment of the applicable water quality objectives for sediment. The Redwood Creek watershed was listed on California's Clean Water Act (CWA) Section 303(d) lists beginning in 1992, and most recently in 1998, as water quality limited due to sedimentation. The level of sedimentation in the Redwood Creek watershed was judged to exceed the existing water quality objectives (WQO's) necessary to protect the beneficial uses of the watershed, particularly the cold water fishery.

It is expected that implementation of the WQAS also will result in an ancillary benefit of reductio in ongoing risks tostreamside redwoods in Redwood National and State Parks from consequent changes in stream channel structure and shape.

The requirements of a TMDL are described in 40 CFR 130.2 and 130.7 and Section 303(d) of the CWA, as well as in various guidance documents (e.g., U.S. EPA, 1991). A TMDL is defined as "the sum of the individual wasteload allocations for point sources and load allocations for nonpoint sources and natural background" (40 CFR 130.2) such that the capacity of the waterbody to assimilate pollutant loadings (the Loading Capacity) is not exceeded. That is,

TMDL =GWLAs +GLAs +MOS

where G = the sum, WLAs = waste load allocations from point sources, and LAs= load allocations from nonpoint sources (including natural background), and MOS = margin of safety. A TMDL is also required to be developed with seasonal variations, including a margin of safety to address uncertainty in the analysis, and consider critical conditions of flow and other key water quality parameters.

The Redwood Creek WQAS incorporates elements which address the statutory and regulatory requirements for a TMDL along with needed documentation of the basis for the TMDL. These elements include an assessment of the pollutant problems and impacts on the beneficial uses, development of instream numeric targets that interpret and apply the WQO's, an assessment of the sources of the pollutant, and estimation of loading capacity and associated load allocations to meet WQO's.

Implementation Plan Component

Pursuant to Clean Water Act Section 303(e) and federal regulations at 40 CFR 130.6, states are required to develop water quality management plans to implement water quality control measures including TMDLs. In addition, State law requires that the Basin Plan include "a program of implementation needed for achieving water quality objectives." (Water Code Section 13050(j)). The Implementation Plan component of the WQAS addresses these requirements by requiring landowners to develop erosion control plans to reduce sediment discharges to Redwood Creek and its tributaries, and to comply with a prohibition on waste discharge to Redwood Creek.

State and Federal Government Roles

Regional Water Board is establishing the TMDL and Implementation Plan to meet the requirements of Clean Water Act Sections 303(d) and (e), along with state requirements.

The Environmental Protection Agency (EPA) has oversight authority for the 303(d) program and is required to review and either approve or disapprove the TMDLs submitted by states. If the EPA disapproves a TMDL submitted by a state, the EPA is required to establish a TMDL for that waterbody.

Pursuant to a consent decree entered in the United States District Court, Northern District of California (Pacific Coast Federation of Fishermen's Associations, et al. v. Marcus, No. 95-4474 MHP, March 11, 1997), EPA committed to assuring that TMDLs would be established for 18 rivers by December 31, 2007. Pursuant to the consent decree, EPA developed a Supplemental TMDL Establishment Schedule which set December 31, 1998, as the deadline for the establishment of a TMDL for the Redwood Creek. The Regional Water Board is establishing this TMDL consistent with that deadline, along with the implementation provisions needed to carry out the TMDL.

Under the consent decree, if the State of California fails to establish a TMDL by the deadline in the Supplemental TMDL Establishment Schedule, EPA must establish a TMDL for that waterbody by the deadline in the Schedule. If the State does not meet the December 1998 deadline for Redwood Creek, EPA will have to establish a TMDL pursuant to the Consent Decree.

The State is required to incorporate the TMDL, along with appropriate implementation measures, into the State Water Quality Management Plan (40 CFR 130.6(c)(1), 130.7). The Regional Water Board Basin Plan, and applicable state-wide plans, serve as California's Water Quality Management Plan governing the Redwood Creek watershed.

A Note On Methods Used To Develop the TMDL and Implementation Plan

Redwood Creek has been extensively studied by many researchers for over 30 years. As a result, substantial information and data concerning erosion causes, trends, and impacts have been developed for the watershed, particularly by scientists associated with Redwood National and State

Parks (RNP). The Redwood Creek TMDL is based on this existing body of analysis, supplemented by the expert judgment offered by several researchers at RNP.

The State recognizes that erosion processes which are responsible for sediment inputs to the system are highly dynamic and variable from year to year and in different locations in the basin. The main driving factor influencing variation in erosion and sediment inputs from year to year is variability in precipitation and, particularly, periodic high magnitude storms. This TMDL analysis used historical data for sediment loading, stream flows, and stream responses to erosional impacts. It is difficult to predict future erosion and associated impacts based on past erosion patterns and a dynamic predictive model of future erosion amounts, timing, and locations was not developed. However, this TMDL does account for temporal and spatial variability in erosion and stream responses in several ways:

Temporal Considerations

TWO SETS OF indicators were selected for use in numeric target development and follow-up monitoring. THE FIRST SET IS believed to integrate cumulative effects over annual OR LONGER timeframes (e.g. annual low flow measurements of stream bottom composition AND SURVEYS OF LANDSLIDE DISTRIBUTION AFTER MAJOR STORMS). THESE INDICATORS ARE IMPORTANT BECAUSE THEY ARE CAPABLE OF INDICATING, OVER THE LONG TERM, WHETHER IMPLEMENTATION OF THE TMDL HAS ACHIEVED ITS DESIRED LONG-TERM EFFECTS. THESE ARE THE INDICATORS THAT ARE USEFUL FOR TRACKING THE SLOW CHANGES IN CHANNEL FORM EXPECTED OVER THE LONG TERM. HOWEVER, THESE KINDS OF INDICATORS ARE NOT CAPABLE OF PROVIDING FEEDBACK OVER THE TIME-SCALE NECESSARY TO DETECT ON-GOING OR EMERGING PROBLEMS, OR TO IDENTIFY THE SPECIFIC SOURCES OF WATER QUALITY PROBLEMS.

THE SECOND SET OF INDICATORS IS DESIGNED TO ADDRESS THESE REAL-TIME NEEDS BY MEASURING instantaneous conditions (e.g. turbidity). THE MOST IMPORTANT INDICATORS OF IMPACTS TO WATER QUALITY ARE THOSE RELATED TO TURBIDITY AND SUSPENDED SEDIMENT. THE STANDARD METHOD FOR DETERMINING ATTAINMENT OF OBJECTIVES RELATED TO TURBIDITY AND SUSPENDED SEDIMENT INDICATORS IS THE USE OF "SEDIMENT RATING CURVES", WHICH COMBINE MEASUREMENTS OF TURBIDITY OR SEDIMENT RESPONSE FROM INDIVIDUAL STORM EVENTS TO DEFINE A RELATIONSHIP BETWEEN SEDIMENT LEVEL AND DISCHARGE. LATER MEASUREMENTS CAN BE COMPARED STATISTICLY WITH THE DEFINED RELATIONSHIP TO DETERMINE WHETHER REAL-TIME CONDITIONS ARE WITHIN THE RANGE DEFINED BY THE TMDL. THIS APPROACH ALLOWS TRENDS TO BE DISCERNED WITHIN SHORTER (2-5 YEAR) TIME FRAMES, AND ALSO ALLOWS REAL-TIME MONITORING OF COMPLIANCE.

FOR THE FIRST SET OF INDICATORS, numeric targets (goals for instream indicators), the total allowable load, and specific load allocations are expressed in terms of 10 year rolling averages in recognition that trends are not discernible within shorter time frames and to allow for natural variation due to seasonal and annual differences.

FOR THE SECOND SET OF INDICATORS, TURBIDITY RATING CURVES ALLOW A MORE PRECISE DEFINITION OF NUMERIC TARGETS THAT DIRECTLY REFLECT THE

OBJECTIVES OF THE BASIN PLAN. TURBIDITY RATING CURVES DEFINED FOR LOW-DISTURBANCE TRIBUTARIES ON A PARTICULAR GEOLOGIC UNIT PROVIDE A STANDARD WITH WHICH TO COMPARE TURBIDITY RATING CURVES AT OTHER SITES ON THE SAME GEOLOGIC UNIT TO DETERMINE WHETHER THOSE SITES' RATING CURVES ARE WITHIN 20% OF BACKGROUND LEVELS. DEVIATIONS FROM BASIN PLAN OBJECTIVES ARE EASILY DETECTED BY COMPARING THE LEVELS OF THE CURVES.

The TMDL is a phased TMDL (EPA 1991), which provides for an iterative, adaptive approach to ongoing watershed assessment and management planning. The phased approach enables the TMDL to be adjusted as our understanding of watershed processes increases and in response to future events which may create the need to adjust the numeric targets, total allowable loads, and associated load allocations.

Spatial Considerations

The TMDL was developed based primarily on analysis of conditions in different tributaries to Redwood Creek which are representative of different geologies, CUTTING HISTORIES, and associated vulnerabilities to erosion.

For some indicators, separate numeric targets were identified for different parts of the watershed to account for differences in geomorphic conditions and habitat issues in different parts of the watershed. That is, separate numeric targets for fish rearing habitat were developed for tributaries versus the mainstem of Redwood Creek.

WATERSHED OVERVIEW

This section is based primarily on information contained in the draft Redwood Creek Watershed Analysis (NPS, 1997) and other publications by RNSP researchers.

Redwood Creek watershed is a 285 square mile forested watershed in Humboldt County, California. Redwood Creek flows into the Pacific Ocean near Orick. The drainage area upstream of the U.S. Geological Survey stream gauging station at Orick is 278 square miles (Figure 1). The Redwood Creek watershed consists mostly of mountainous, forested terrain from sea level to about 5,300 feet elevation. Primary land uses are tourism and fishing on park lands and timber and livestock production on lands upstream of Redwood National and State Parks. The watershed is narrow and elongated, about 65 miles in length, from 4 to 7 miles wide.

The cold water fishery is identified by the Regional Water Board as a beneficial use of the Redwood Creek watershed. The creek historically supported large numbers of coho salmon, chinook salmon, steelhead trout, and other fish species. Coho salmon, a species native to the Redwood Creek, is listed under the federal Endangered Species Act as a threatened species. In addition, steelhead and chinook salmon populations have declined significantly in the watershed. Sedimentation due to natural geologic instabilities, past and present land use practices, and other factors has contributed to the reduction and loss of habitat necessary to support cold water fish.

Climate and Hydrology

The climate of the Redwood Creek watershed is Mediterranean, with mild, wet winters (November to March), and warm, dry summers. Mean annual precipitation is roughly 80 inches, mostly rain, with snow frequently at altitudes above 1,600 feet.

Streamflow in Redwood Creek is highly variable from year to year as a result of annual rainfall variations. Streamflow also varies seasonally, owing to the highly seasonal distribution of rainfall. Winter flood flows can be as much as four orders of magnitude higher than summer low flows. Snowmelt can increase streamflow peaks during rain-on-snow events, as occurred in 1964.

Floods are critical events for the resources of Redwood Creek because they erode hillslopes, reshape channels, and transport large proportions of fluvial sediment loads. Recent large floods occurred in 1953, 1955, 1964, 1972 (two floods), and 1975. The 1964 storm was a regionally significant event that caused major damage to towns, highways, and other structures, as well as significant hillslope erosion and channel changes.

No large floods occurred after 1975, until the recent 11-year return period flood in January of 1997. During January 1997, the relatively small 11-year return period flood initiated debris torrents of mud, boulders, and whole trees directly into Redwood Creek adjacent to Tall Trees Grove; the effects of a major storm would be orders of magnitude more severe. Within the time period from 1975 to 2015, there is an 80% chance of a 25-year flood. It has been 23 years since the last 25-year flood in Redwood Creek. It has been 34 years since the last 50-year flood, and erosion potential in this watershed from such a storm is estimated at more than 5 million cubic yards. Of this, 90% is from the private roads upstream from the park. HOWEVER, STUDIES OF NEARBY WATERSHEDS (PWA: JORDAN CREEK, BEAR CREEK, N.F. ELK RIVER) ON SIMILAR SOILS INDICATE THAT LANDSLIDE RATES INCREASE BY 300% TO 1300% FOLLOWING SILVICULTURAL TREATMENT, INDICATING THE NEED FOR

MONITORING OF FUTURE LANDSLIDE DISTRIBUTION AND RATE AS A COMPONENT OF THE TMDL.

FOREST CANOPY REMOVAL DECREASES RAINFALL INTERCEPTION LOSSES DURING LARGE STORMS BY MORE THAN 15%, THEREBY INCREASING PEAK FLOWS AND MASS WASTING RATES DUE TO THE MORE FREQUENT HILLSLOPE SATURATION. INCREASED PEAK FLOWS ACCELERATE SURFACE EROSION, GULLY EROSION AND BANK FAILURE. IT IS NECESSARY TO VERIFY THE MASS WASTING RESPONSE TO FOREST CANOPY REMOVAL THOUGH SEQUENTIAL AERIAL PHOTO ANALYSIS. IN THIS WAY THE MAGNITUDE OF THE PATTERN EXPRESSED IN REDWOOD CREEK CAN BE DEFINED. Within the time period from 1964 to 2014, there is a 64% chance of a 50-year flood.

Geology

Geologic structure in the Redwood Creek watershed is governed by several parallel north-northwest trending faults. For much of its length, the channel of Redwood Creek closely follows the Grogan Fault. Redwood Creek watershed is characterized by relative steep, unstable hillslopes, very steep inner gorge slopes along much of the mainstem and some tributaries, and narrow valley bottoms. Most of the Redwood Creek watershed has experienced uplift over the past several hundred thousand years. The watershed is underlain by the Franciscan complex of unmetamorphosed sandstones, mudstones, schists, and scattered blocks of other rock types. In general, slopes west of the Creek (which generally follows the Grogan fault) are underlain by schist, and slopes east of the Creek are underlain by sandstones and mudstones (Figure 2).

A very high percentage of the land area of Redwood Creek watershed is underlain by rock types which are relatively weak and susceptible to erosion and mass soil movements (e.g., schists and mudstones). Remaining areas of the watershed which are underlain by more competent rock types (e.g. interbedded sandstone/mudstones) are somewhat more resistant to erosion, but form steep slopes which are susceptible to rapid, shallow landsliding processes.

Plants and Animals

The natural vegetation of the Redwood Creek watershed consists mostly of coniferous forest, but also includes areas of oak woodland and grassland prairie. The distribution of plant communities depends primarily on water availability and fire regime.

Old-growth forest currently covers 24,315 acres in the watershed, equivalent to 14% of its total area. Near the coast, the most common forest tree is the Sitka spruce. Most of the lower-watershed forest, however, is dominated by coast redwoods. Farther inland, where summer temperatures are higher and fog is less frequent, douglas fir is more common than redwood. Several hardwood species grow in association with both redwood and douglas fir, including big-leaf maple, red alder, tanbark oak, madrone, and bay. Prairies and oak woodlands occur on south- and west-facing ridgetops and hillslopes on the east side of Redwood Creek.

Approximately 250 species of wildlife (amphibians, reptiles, mammals, and birds) are known to occupy habitats found in the Redwood Creek watershed. Thirty three species of wildlife are identified as species of special concern (threatened, endangered or sensitive to human activities, see NPS (1998) for details).

The Redwood Creek watershed provides aquatic habitat for a variety of fish species. Anadromous and resident salmonids identified in Redwood Creek include steelhead and rainbow trout, coastal cutthroat trout, coho salmon, and chinook salmon. Other fish identified or reported include the tidewater goby, Humboldt sucker, threespine stickleback, coastrange sculpin, Pacific lamprey, and eulachon. Five species of fish have been listed as species of special concern, endangered species, or sensitive species by federal and state agencies

Summary of Existing Conditions
The Draft Redwood Creek Watershed Analysis (RNP 1997) provides a summary analysis of existing stream conditions. In general, stream channels in the Redwood Creek basin are wider, shallower, and more homogeneous than is desirable or were historically present.

1. Stream Channel Conditions and Fish Habitat Impacts

Stream channel structure along the mainstem of Redwood Creek and its tributary watersheds has changed substantially over the last 40 years. Key changes in the mainstem of Redwood Creek include (1) increases in the volume of stored sediment, (2) decreases in pool numbers and depth, (3) increases in stream width and decreases in stream depth, (4) reduced recruitment of large woody debris, (5) deposition of high levels of fine sediments on the stream bottom, (6) reduced volumes of large woody debris, 7) INCREASED CHRONIC TURBIDITY, 8) INCREASED SCOURING OF SUBSTRATE DUE TO INCREASED PEAK FLOWS AND DECREASED BED MATERIAL SIZE.

Stored Sediment

More sediment has been supplied to the low gradient reaches of the mainstem than it can effectively transport. Low gradient reaches of the mainstem Redwood Creek have acted as long term repositories of eroded sediment which originated in upstream areas. Although the creek is apparently beginning to downcut through aggraded sediments in its lower watershed reaches, this stored sediment has the potential to affect channel structure and habitat values for centuries. In contrast, the higher gradient mainstem reaches in the upper watershed have removed about half the sediment deposited by the 1964 flood within 20 years (RNP 1998).

Pool Distribution and Depth

Most mainstem pools were filled by sediments born primarily by the 1964 flood, and to a lesser extent by other high magnitude events between 1954 and 1975. Pool frequency and mean depth appeared to increase since 1975 as the creek began to move out previously deposited sediment loads, and pool recovery is more apparent in the upper watershed. However, many pools were again filled by sediments following the moderate 1997 storm season. Reduced pool frequency and depth impairs rearing habitat by reducing availability of cool water refuges and increasing predation.

Channel Width and Depth

Many reaches of Redwood Creek became substantially wider and shallower in response to excessive sediment inputs and destructive flood flows which occurred between the mid 1950s and mid 1970s. Stream width increased and depth decreased in response to streambank erosion and channel aggradation. Although many reaches of Redwood Creek have begun to downcut through aggraded sediments (especially in the middle and upper watershed), stream widths have not decreased substantially. Fish habitat impacts associated with increased width and decreased depth include increases in water temperature, decreased cover to hide from prey, and increased difficulty in moving up and down the stream in search of food and cool water refugia. In addition, aggraded sediment deposits have formed "deltas" at the mouths of many tributaries which impede fish passage upstream into tributaries. Finally, as the creek has widened and riparian timber has been harvested, canopy coverage of the stream has been reduced substantially, contributing to water temperature increases.

Fine Sediments

Although limited data are available concerning stream substrate composition in Redwood Creek, it appears that there is a slight trend toward coarsening of bed material since the 1970s. However, levels of fine sediment appear to be higher than desirable for successful fish spawning in many reaches of Redwood Creek, principally in the lower watershed.

Large Woody Debris

Large woody debris (LWD) in North Coast streams provides multiple functions which are key to the maintenance of healthy stream habitat and the moderation of sedimentation impacts on those streams. Presence of adequate LWD is a key factor in pool formation, sediment storage and metering, and nutrient loading in many streams. Due to extensive harvesting of riparian forests along Redwood Creek and its tributaries along with extensive streambank erosion, recruitment of LWD is well below historic levels needed to support healthy fish habitat and to moderate sediment transport.

[this was pretty redundant]Recruitment of large woody debris and nutrients are probably well below historic levels. This condition is likely to persist into the future as deciduous willows and alders take the place of evergreen conifers along much of the mainstem and tributaries, and as large conifers along watercourses in the upper basin are harvested (NPS, 1997). Willows and alders generally yield less durable LWD than conifers.

CHRONIC TURBIDITY
[WRITE SOMETHING HERE]

2. Hillslope Conditions

Timber harvesting is the most widespread land use in Redwood Creek watershed. Over 85% of the watershed upstream of the park has been logged, including about 30% which was logged between 1978-1992. About three-quarters of this recently logged area was logged using intensive silvicultural methods which remove all or almost all trees from the harvest area. Substantial areas of the park were intensively logged prior to their inclusion in the park. Harvested areas remain at greater risk of increased erosion (principally through landsliding) for at least a year or two following harvest, and possibly for longer periods of time. It is expected that timber harvesting of second growth timber in the upper watershed will continue in the future, so erosion potential associated with these harvests will need to be addressed through the TMDL.

Most of the likely future erosion potential in the watershed caused by human activity is associated with THE SPATIAL DISTRIBUTION AND TEMPORAL INTENSITY OF SILVICULTURAL ACTIVITIES AND THE CONSTRUCTION, USE, AND MAINTENANCE OF logging roads and skid trails, although roads constructed for other purposes also pose significant erosion potential. Roughly 1400 miles of forest roads and over 5000 miles of skid trails have been build within the watershed. The table below depicts the miles of roads, area in square miles, and road densities within the Redwood National and State Park lands and on private lands for the Redwood Creek watershed. Private lands upstream of the park have approximately 1,100 miles of logging roads on approximately 163 square miles, a density of approximately 6.8 miles/square mile, compared to approximately 230 miles of roads on approximately 115 square miles of parklands, a density of approximately 2.0 miles/square mile. Private lands contain almost times the road mileage at 3.4 times the road density of those found in the park, on a land base about 1.4 times that of the park. Of these 1,100 miles of private roads, only about half were being maintained as of 1992 (NPS, 1997).. Also, a very high percentage of skid trails upstream of the park are not properly maintained nor have been abandoned. Following the most recent large storms on January 1, 1997, large landslide failures were observed throughout the Redwood Creek watershed, and most were associated with roads. The Redwood Creek Watershed Analysis contains a detailed analysis of the status and condition of existing roads, and concludes that remaining erosion potential associated with poorly designed and maintained roads remains the largest future erosion source in the watershed which can be controlled. Although there has been some recovery in the Redwood Creek and tributary channels, it is expected that a very high percentage of improperly constructed or maintained roads will fail during the next high magnitude storm. Unless corrected through road upgrading, maintenance, and/or decommissioning, such road failures are expected to cause substantial direct erosion (through crossing failures, stream diversions, etc.) and indirect erosion events (e.g. gully formation and mass wasting events).

1. Miles of Road, excluding highways, and county roads	(miles):
(a)Redwood Creek watershed, upstream of Orick	1345 (includes b & d below)
(b)private lands, upper watershed	1115
(c)park lands, lower watershed, only Redwood Creek	140 (excludes e)
(d)park lands, lower watershed, including Prairie Creek Watershed	230 (includes c & e)
(e)park lands, Prairie Creek Watershed	90
2. Area	(square miles):
Redwood Creek watershed, upstream of Orick	278
private lands, upper watershed	163
park lands, lower watershed, mainstem Redwood Creek	76
park lands, lower watershed, including Prairie Creek Watershed	115
park lands, Prairie Creek Watershed	39
3. Road Density (miles/square mile):	
Redwood Creek, upstream of Orick	4.8
private lands, upper watershed	6.8
park lands, lower watershed, mainstem Redwood Creek	1.8
park lands, lower watershed, including Prairie Creek Watershed	2.0
park lands, Prairie Creek Watershed	2.3
Total area Redwood Creek Watershed	282mi^2
Total area Prairie Creek Watershed	40 mi^2

Other continuing land uses in the watershed pose less substantial erosion potential although potential impacts could be significant in local settings. State and county roads pose significant erosion potential in some locations. Ranching operations and residential property management may also have the potential to cause significant erosion, particularly in locations where livestock access contributes to streambank erosion.

Land Use and Sedimentation Issues

Relationships among floods, sediment, and land use have been central to the debate over resource protection in the Redwood Creek watershed. Damage to forest resources, fish, and other resources coincided with both intensive land use and a series of large storms that were accompanied by widespread flooding and erosion. Erosion rates in northwestern California are naturally high, and land use has significantly increased erosion above natural levels associated with storms

In the Redwood Creek Watershed, the large number of improperly designed and maintained roads, landings and skid trails caused: 1) increased surface erosion and fine sediment production and delivery and 2) an increased potential for stream diversions (stream channel capture), rill and gully erosion, and road related landslides with corresponding increases in sediment production and delivery. Timber harvest operations on unstable slopes and removal of riparian vegetation have also contributed to increased erosion and sediment production.

PROBLEM STATEMENT

Water Quality Objectives

Water quality objectives (sometimes referred to as standards) adopted for the Redwood Creek basin are contained in the Basin Plan. The beneficial uses of water for Redwood Creek are also described in the Basin Plan as either existing or potential. The water quality objectives are designed to protect the most sensitive of the beneficial uses.

The beneficial uses addressed in the Redwood Creek TMDL include: cold freshwater habitat (COLD); migration of aquatic organisms (MIGR); estuarine habitat (EST); uses of water for community, military, or individual systems including, but not limited to drinking water supply (MUN); uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened or endangered (RARE); and spawning, reproduction, and/or early development (SPAWN). The water quality objectives addressed include settleable material ("Water shall not contain substances that result in deposition of material that causes nuisance or adversely affect beneficial uses") and sediment ("The suspended sediment load and suspended sediment discharge rate of surface water shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.").

Discharges of sediment are addressed by the discharge prohibition contained in the Basin Plan as follows:

> "1. The discharge of soil, silt, bark, slash, sawdust, or other organic material from any logging, construction, or associated activity of whatever nature into any stream or watercourse in the basin in quantities deleterious to fish, wildlife, or other beneficial uses is prohibited.
>
> "2. The placing or disposal of soil, silt, bark, slash, sawdust, or other organic material from any logging, construction, or associated activity of whatever nature where such material could pass into any stream or watercourse in the basin in quantities which could be deleterious to fish, wildlife, or other beneficial uses is prohibited.

Beneficial Use Issue

Salmonids are born in fresh water streams where they spend one to several years of their lives feeding, growing, and hiding from predators. Once they are large enough, fresh water salmonids undergo a physiological change which allows them to swim out to the ocean where they then spend the next one to several years. Salmonids return to the streams in which they were born to lay eggs and begin the life cycle again. Incubation of the eggs requires gravels free from excessive fine sediment to develop into free-swimming fish. They also require clean riffles for insect food sources and deep pools for the young fish to feed and grow while protected from predators.

Redwood Creek is largely free of the effects of non-native aquatic species or hatchery stocks which might impact the native fishery. Although numbers of native salmonid species present in Redwood Creek have declined substantially (by perhaps 90% by the mid-1970s) [citation?], remnant populations of coho, winter chinook, winter and summer steelhead, and cutthroat trout are still present. Coho salmon were listed under the federal Endangered Species Act as a threatened species by rule published on May 6, 1997 by the Secretary of the Department of Commerce. Redwood Creek is located within the Evolutionarily Significant Unit (ESU) known as the Southern Oregon/Northern California Coast where coho salmon were listed.

Redwood Creek's ability to support fish populations is determined by habitat availability and quality. Habitat availability is limited by streamflow, stream gradients, and physical barriers such as boulders and log jams. Habitat quality is limited by channel bottom composition, pool structure, water temperature, dissolved oxygen, food supply, and predation (NPS 1998). However, the WQAS only addresses habitat quality impacts associated with excessive sediment discharges. The key habitat problems in Redwood Creek associated with sedimentation appear to be pool quality, gravel quality (for spawning and food production), and changes in channel structure which contribute to temperature elevation. [what about bank erosion??]

Residents in the upper Redwood Creek basin commonly have instream domestic water intakes. These water supplies can be adversely impacted by high sediment loads, but that beneficial use is not currently impaired. Excessive sediment may result in turbidity, adverse tastes, and nuisance condition due to clogging of filters. It is anticipated that implementation of the WQAS will also help protect drinking water.

General Problem Statement

The Redwood Creek watershed has experienced a reduction in the quality and quantity of instream habitat which is capable of supporting the cold water fishery, particularly that of coho salmon, chinook salmon, and steelhead. Controllable factors contributing to this habitat loss include the acceleration of sediment production and delivery due to land management activities, including existing roads, and the loss of instream channel structure necessary to maintain the system's capacity to efficiently store, sort, and transport delivered sediment.

Three important factors in describing the issue of sedimentation are: sediment production, sediment delivery, and sediment transport. Water quality concerns arise when sediment is delivered to the stream in amounts, or to locations that overwhelm the stream's capacity to transport it. WATER QUALITY CONCERNS ALSO ARISE DUE TO CHRONIC DURATIONS OF TURBIDITY AND SUSPENDED SEDIMENT DELIVERY. Such is the case in the Redwood Creek watershed. Habitat niches are filled by sediment and the stream channel is aggraded, in some places. It is important to note, though, that the aggradation of the upper mainstem and most tributaries appears to be reversing-- an indication that the process of recovery has begun. Adequate pool riffle structure and stream cover are still absent in the lower mainstem. Excessive sedimentation has also contributed to habitat degradation in the estuary.

For gravel-bed streams, such as the Redwood Creek, the presence of channel structure plays a crucial role in the efficient storage, sorting, and transport of sediment through the river system. Channel structure takes the form of large woody debris, boulders, armored stream banks, and other structural elements. For streams in the Pacific Northwest, including northern California, large woody debris has been identified as a particularly important structural element. Thus, sediment delivery and instream channel structure, particularly large woody debris, are integral companions in the problems (and solutions) related to sedimentation and the reduction in the quality and quantity of instream habitat.

1. <u>Instream Problem Statements</u>

   1. Fine Sediment in Spawning Gravels

Spawning gravels of the Redwood Creek watershed are impacted and likely to suffer additional impacts by the delivery of fine sediment to the stream which fills the interstices of the framework particles: 1) cementing them in place and reducing their viability as spawning substrate, 2) reducing the oxygen available to fish embryos, 3) reducing intragravel water velocities and the delivery of nutrients to and waste material from the interior of the redd (salmon nest), and 4) impairing the ability of fry (young salmon) to emerge as free-swimming fish. This statement relates to the SPAWN beneficial use and the potential for settleable material to impact spawning substrate or redds.

2. Channel Aggradation

Spawning gravels of the Redwood Creek watershed are impacted by the delivery of fine and coarse sediment to the stream which causes aggradation, the burial of large woody debris and other structural elements, a loss of the stream's ability to effectively sort gravel, and a potential reduction in the dominant particle sizes. This statement relates to the SPAWN and COLD beneficial uses and the potential for sediment and settleable material to impact spawning substrate.

3. Lack of suitable pools for Rearing Habitat

Pools of the Redwood Creek watershed potentially suitable as rearing habitat are impacted by the delivery of fine and coarse sediment to the stream which: 1) reduces the volume of available rearing habitat by filling in pools and burying pool-forming structural elements such as large woody debris, 2) reduces pool depth and therefore the cool water refuge associated with temperature stratification, 3) reduces the availability of fish cover as a result of decreased depths and the burial of large woody debris and other structural elements, and 4) causes loss of surface flow as pools are filled in resulting in less available habitat and protection from predators. This statement relates to the SPAWN and COLD beneficial uses and the potential for sediment and settleable material to impact rearing habitat.

4. Stream Channel Instability

Increased sediment delivery to the Redwood Creek watershed impacts stream channel stability by causing: 1) aggradation, stream channel widening, greater flood potential, and greater stream bank erosion, and 2) the burial of channel structural elements such as large woody debris with a reduction in sediment transport efficiency. This statement relates to the COLD and EST beneficial uses and the potential for sediment to impact stream channel stability and habitat niches.

5. Physical Barriers to Migration

The migration of anadromous fish in the Redwood Creek watershed from the ocean, within the watershed, and back to the ocean is impacted by the presence of migration barriers including shallow or dewatered stream segments due to aggradation (rising stream bed elevation). This statement relates to the MIGR beneficial use and the potential for sediment in the form of aggradation or road fill to prevent the migration of salmonids. (Natural barriers, such as bedrock falls, are not addressed here since they were not created by land management activities and hence are not controllable. Moreover, the sediment TMDL does not address anthropogenic barriers associated with culverts because USEPA does not consider culverts a pollutant for which TMDL preparation is needed (EPA, 1997)).

6. CHRONIC TURBIDTY AND SUSPENDED SEDIMENT IMPACTS TO EMERGENCE, FEEDING, AND REARING

ANADROMOUS FISH ARE VISUAL FEEDERS. FEEDING RATES ARE SIGNIFICANTLY REDUCED AT TURBIDITIES ABOVE 60-100 NTU'S. AND LONG-DURATION HIGH TURBIDITY CONDITIONS LIMIT SALMONIDS' ABILITY TO GROW. REDUCED GROWTH RATE DUE TO REDUCED FEEDING CONTRIBUTES TO SMALLER SIZED FISH ENTERING THE OCEAN, AND SMALL-SIZED FISH HAVE HIGHER RATES OF OCEAN MORTALITY. UNDER SEVERE CONDITIONS, SUSPENDED SEDIMENT CAUSES MORTALITY DUE TO GILL ABRASION AND RESULTING INFECTION.

2. Upslope Problem Statements

1. Improperly Designed or Maintained Roads

The large number of improperly designed and maintained roads, landings and skid trails in the Redwood Creek watershed causes: 1) increased surface erosion and fine sediment production and delivery and 2) an increased potential for stream diversions (stream channel capture), rill and gully erosion, and road related landslides with corresponding increases in sediment production and delivery. This statement relates to the COLD beneficial use and the potential for sediment and settleable matter to impact stream channel stability and habitat niches.

2. Sediment from Unstable Areas

Timber harvest operations on unstable slopes (e.g., inner gorges, headwall swales, active or potentially active landslides, or steep slopes) in the Redwood Creek watershed cause increased landsliding and the production and delivery of fine and coarse sediment. In addition, agricultural operations in streamside areas increase streambank erosion in localized settings. This statement relates to the COLD beneficial use and the potential for sediment and settleable matter to impact stream channel stability and habitat niches.

3. Removal of Riparian Trees and Loss of Large Woody Debris

The removal of vegetation (particularly large conifers) from the riparian zone of the Redwood Creek watershed causes: 1) a loss of stream bank stability and increased stream bank erosion, 2) a loss of sediment filtering capacity and increases in sediment delivery, and 3) a reduction in the potential for large woody debris recruitment to the stream and in the stream's sediment transport efficiency. This statement relates to the COLD beneficial use and the potential for sediment and settleable matter to impact stream channel stability and habitat niches.

4. INCREASED FLOOD DISCHARGES

REMOVAL OF FOREST CANOPY BY LOGGING HAS BEEN SHOWN TO REDUCE RAINFALL INTERCEPTION LOSS BY 15% OR MORE DURING LARGE STORMS AND SO INCREASING THE EFFECTIVE RAINFALL OF THE STORM BY AN EQUIVALENT AMOUNT. THIS LEVEL OF CHANGE CAN SEVERELY INCREASE THE FREQUENCY OF FLOODING IN HEAVILY LOGGED TRIBUTARY STREAMS, THEREBY INCREASING THE POTENTIAL FOR CHANNEL DESTABILIZATION AND STREAMBANK LANDSLIDING.

NUMERIC TARGETS

Section 303(d)(1)(C) of the Clean Water Act states that TMDLs "shall be established at a level necessary to implement the applicable water quality standards...." The numeric targets developed for the Redwood Creek TMDL are intended to interpret the narrative water quality standards adopted in the Basin Plan (1994). The numeric targets are not directly enforceable. Rather, they are tools which assist in analyzing the extent of the current problem. They also serve as monitoring tools which will assist in evaluating whether the load reductions called for in the TMDL are being attained and whether these load reductions are effective in bringing about needed improvements in aquatic habitat quality.

Instream numeric targets, as included in the TMDL, represent the optimal stream habitat conditions for salmonid reproductive success. Instream targets provide a vital set of measures of whether, in the long run, beneficial uses impacted by sedimentation are recovering.

The numeric targets are based on scientific literature, available monitoring data for the watershed and best professional judgment. When implemented, the TMDL should fully meet these targets and, as a result, the WQO's. Table 1 in Appendix B depicts the numeric targets.

Numeric targets interpret existing narrative water quality objectives in order to:

- assist in estimating Redwood Creek's capacity to receive future sediment inputs and still support beneficial uses,
- compare existing and target conditions for sediment related indicators,
- provide an evaluation framework for analyzing monitoring data collected in the future and making changes in the TMDL and/or Implementation Plan in response, and
- assist in evaluating whether land management and restoration actions are effective in adequately reducing erosion and subsequent sediment loading to the Creek.

The indicators for which the State is establishing instream numeric targets include percent fines <0.85 mm, percent fines <6.5 mm, mean surface particle size (d_{50}), percentage of mainstem creek length in riffles, residual large woody debris, and mean residual pool depth. Separate pool depth targets are established for the mainstem and for tributaries to Redwood Creek to reflect the differences in stream sizes and related differences in desirable pool characteristics. In addition, the stream riffle target is being set only for the lower gradient part of Redwood Creek to reflect the fact that pool riffle structure may be substantially different in higher gradient streams. Scientific literature suggests that these indicators are the most easily linked to fish habitat conditions which support salmonids and can assist in evaluating long term impacts of upslope activities and erosion reduction efforts (Knopp, 1993, Chapman, 1988, Peterson, et.al. 1992, NMFS, 1997).

The targets are monitoring and evaluation goals intended to represent the desired condition where sediment is not a limiting factor for salmonid production. The targets are not enforceable. In contrast, the TMDL is set for the compliance point at Orick and is, along with the associated allocations, enforceable. Insufficient information was available to reliably stratify the TMDL or allocations based on geologic settings.

Some of the selected indicators and target values are sensitive to variations in conditions in different areas of the watershed which are influenced by differences in geology and stream morphology. However, the indicators and associated numeric targets are relatively insensitive to probable annual variations in future sediment loading and impacts over time. It would be desirable to use more dynamic indicators which set erosion reduction and habitat improvement goals as a function of the factors which determine year-to-year variations in sediment loading and stream responses. Ideally, the TMDL would include indicators which directly account for variations in precipitation and resultant runoff and flows. Use of this type of indicator would enable analysts to distinguish changes in erosion and instream effects associated with land management actions from changes attributable to differences in runoff intensity. This approach could make it easier to evaluate the effectiveness of the TMDL based on limited data. Because such indicators could not be identified for this TMDL, most of the numeric targets are expressed as ten year rolling averages. This approach helps ensure that conclusions concerning watershed responses to erosion control actions are not drawn prematurely. The drawback of this approach is that we must wait several years before we will be able to complete this critical evaluation of TMDL effectiveness.

1. Percent Fines <0.85 mm

Once the eggs are laid and fertilized, the spawners cover the redds with material from upstream, including clean gravels and cobbles. The interstitial spaces between the particles allow for water to flow into the interior cavity where dissolved oxygen, needed by the growing embryos, is replenished. Similarly, the interstitial spaces allow water to flow out of the interior cavity carrying away metabolic wastes. However, fine particles either delivered to the stream or mobilized by storm flow can intrude into those interstitial spaces, blocking the flow of oxygen into the redd and the metabolic wastes out of it. The reduced permeability into and out of the redd results in a reduction in the rate of embryo survival.

a. Numeric Target

The numeric target for fines <.85mm for Redwood Creek is less than or equal to 14%. The target should be monitored at stream reaches around existing monumented cross sections to be selected during the design of the monitoring plan. The target is selected as the midpoint between the percentages of fines reported in unmanaged streams in the Peterson (1992) and Burns (1970) studies. The target takes into account that the 11% fines <0.85 mm which was observed in unmanaged streams in the Pacific Northwest (Peterson et al., 1992) is probably lower than would be expected in California. On the other hand, the 17% fines <0.85 mm which was seen in unmanaged California streams beginning in 1967 (Burns, 1970) is probably too high given the tremendous sediment loads which were discharged to streams as a result of the 1964 storms. In addition, Tappel and Bjorn (1983) predicted that 14% fines <0.85 mm in combination with about 30% fines <9.5mm would provide an average of 50% survival to emergence for steelhead and an average of 70% survival to emergence for chinook salmon. These appear to be acceptable rates of survival to emergence. The literature sources reviewed in setting the target generally support the 14% target level as reasonably protective.

b. Existing Conditions

Fine sediment size fractions are difficult to measure accurately. The percentage of fine sediment in the channel bottom is often measured through various bulk sampling methods which gather both surface and subsurface sediments from the stream bottom. No bulk sampling data has been published for Redwood Creek; however, the fraction of fine sediments <2 mm commonly exceeds 20% (personal communication with Mary Ann Madej of the USGS). Surface particle size distributions can also be measured through the pebble count method. Table 5 in Appendix B is a summary of unpublished fine sediment monitoring data collected by USGS and Redwood National and State Parks in 1979 and again in 1994 at 8 monitoring sites along the mainstem of lower and middle Redwood Creek. Table 5 reports data for the size fractions <2mm and <8mm because they are closest to the sizes selected for numeric targets in this TMDL. It should be noted that the pebble count method is not designed to accurately measure very fine sands and the results are not reliable estimates for the stream as a whole or for the recent past. In addition, monitoring was conducted at a relatively small number of sites on only 2 occasions. For these reasons, firm conclusions concerning actual past or present conditions for fine sediment in Redwood Creek should not be drawn based on this limited data set. These data are presented here to provide a general sense of substrate surface particle sizes observed in 1979 and 1994. Because fines are often winnowed from the surface by stream flow, the fraction of fine sediment is expected to be higher when subsurface fines are also measured, as is done through bulk sampling methods (Lisle and Madej, 1992).

c. Comparison of Numeric Target and Existing Conditions

A comparison of the numeric target and existing information helps provide information on the extent of the problem as well as the sediment reduction needed to meet water quality standards. However, it was infeasible to conduct a quantitative comparison of the numeric target and existing conditions because inadequate reliable data were available. It appears that levels of very fine sediment in Redwood Creek exceed the numeric target to a moderate extent. It also appears that fine sediment levels are higher in the lower reaches of the creek than in the upstream reaches.

2. <u>Percent fines <6.5 mm</u>

After 4 to 6 weeks, the embryos are ready to emerge from the gravel as fry (young swimming fish). The presence of fine sediment in the gravel interstices can impede fry emergence. However, the size of fine particles likely to fill the interstices of redds sufficient to block passage of fry are larger than those likely to suffocate embryos. That is, particles ranging from 0.85 mm to 9.5 mm are capable of blocking fry emergence, depending on the sizes and angularity of the framework particles, while still allowing sufficient water flow through the gravels to support embryo development. Besides a correlation between percent fines and the rate of survival to emergence, there is also a correlation between percent fines and the length of incubation; i.e., the amount of time it takes for the fry to emerge from the egg. Percent fines is also inversely related to the size of emerging fry (Chapman, 1988). Each of these factors impact the ultimate survivability of the embryos and fry.

a. Numeric Target

<u>The numeric target for fines <6.5 mm is less than or equal to 30% for Redwood Creek</u>. The lower watershed target should be monitored at stream reaches around existing monumented cross sections to be identified during the design of the monitoring program. The numeric target was selected based on a review of literature which evaluated the relationship between fines <6.5mm and survival to emergence rates for salmonids. Research results concerning the relationship between salmonid survival to emergence and levels of fines <6.5mm are relatively consistent. Tappel and Bjorn (1983) predicted that 30% fines <9.5mm in combination with 14% fines < 0.85mm would provide an average of 50% survival to emergence for steelhead. The same study predicted that 32% fines <9.5mm in combination with 14% fines < 0.85mm would provide an average of 70% survival to

emergence for chinook salmon. Both steelhead and chinook are expected to have greater emergence success than coho salmon when redds are sedimented. McCuddin (1977) found that the ability of chinook salmon and steelhead trout to emerge from the substrate decreased sharply when sediment less than 6.4mm in diameter comprised more than 20-25% of the substrate. Kondolf (unpublished data), evaluating data from other studies, concluded that if one chooses a 50% survival to emergence rate, the data indicate that fines defined either as <3.35 or <6.5 mm should not comprise more than 30% of substrate composition. Finally, Chapman (1988) reported data from several other studies concerning fine sediment levels in unlogged Oregon watersheds which varied from 27-55%. The 30% target rate appears consistent with the research findings concerning acceptable survival to emergence rates and the levels of fines found in unlogged watersheds.

b. Existing Conditions

Although no specific bulk sampling data have been published for Redwood Creek, the fraction of fine sediments <8 mm commonly exceeds 50% (personal communication with Mary Ann Madej). Table 5 provides existing data for percent fines <8 mm. These data were collected using a surface pebble count method. As noted above, this method does not produce reliable results regarding percentages of very fine sediments due to operator variability, and does not characterize subsurface fines (which are expected to be higher than surface fines due to stream winnowing). In addition, monitoring was conducted at a relatively small number of sites on only 2 occasions. For these reasons, firm conclusions concerning actual past or present conditions for fine sediment in Redwood Creek should not be drawn based on this limited data set.

c. Comparison of Numeric Target and Existing Conditions

Because data are so limited for fine sediment levels in Redwood Creek, it was not feasible to make quantitative comparisons between existing and target conditions. It appears that levels of very fine sediment in Redwood Creek exceed the numeric target to a moderate extent. It also appears that fine sediment levels are higher in the lower reaches of the creek than in the upstream reaches.

3. Pool-Riffle Structure, and Percent Riffles

Juvenile coho require pools for both summer and overwintering rearing. In the summer, pools provide cool, quiet habitat where coho feed and hide from predators. During the winter, off-channel pools provide habitat in which coho and steelhead both can get out of flood flows to avoid being swept downriver and out to sea. Steelhead prefer riffles for rearing during their first summer, but make more regular summer uses of pool habitat as they grow in size. Pool volumes are reduced either when a stream's hydrologic power is reduced (e.g., by increased sediment loading) or by the reduction of pool-forming elements. The number of pool-forming elements can be reduced by modification of the channel morphology (e.g., burial), physical removal (e.g., log-jam removal), reduction in supply (e.g., logging of near stream trees), or a combination of all three causes.

Various pool measures have been used (e.g., pool, frequency, spacing, or area) but are of limited value since the definition of the beginning and end of a pool is quite subjective. It is generally easier to identify riffle locations. Although some riffles are vital to north coast streams, excessive riffle habitat indicates that deep water habitat is deficient. Therefore, because riffles are easier to reliably measure and provide an indirect indicator of pool abundance, this TMDL includes a target for the percentage of creek length in riffles (personal communication with Mary Ann Madej).

a. Numeric Target

The target for percent riffles is no more than 25-30% riffles for creek reaches less than 2% in gradient. This target is based on judgment of a Redwood Park researcher who is very familiar with the pool/riffle structure of Redwood Creek and of north coast rivers with different habitat qualities (personal communication with Mary Ann Madej). The 25-30% level is believed to be consistent with the riffle patterns found in well-functioning north coast streams.
This target only applies in the lower gradient sections of the creek because percent riffles may exceed the target level in steeper streams which support excellent habitat. In the long run, it may prove more effective to measure pool quality and distribution based on statistical analysis of longitudinal profile data collected at monumented reaches of Redwood Creek. This monitoring method has promise in providing a more discriminating indicator of channel roughness and variability, which can be adjusted (normalized) to account for and allow comparisons between streams of different sizes.

b. Existing Conditions and Comparison With Numeric Targets

In the 1970s and early 1980s, riffles comprised from 50 to 70% of observed reaches in study areas. By the mid 1990s, riffles comprised 20 to 40% of observed reaches in study areas. Some reaches of Redwood Creek are still characterized by excessive riffle and insufficient pool structure.

4. Pool Depth

Salmonids rely on deep, cool pools during the rearing stage for protection from predators and as refuges from high temperature water. Pool depth is partly a function of stream disturbance (and associated channel changes) and partly a function of stream size. Pools in larger streams tend to be deeper, on average, than pools in smaller streams (assuming other factors are equal). Flosi and Reynolds (1994) concluded from the Department of Fish and Game's habitat typing data that better California coastal coho streams (stream order 3 or 4) have pools with depths of at least 3 feet.

a. Numeric Target

The numeric target for low flow pool depth is >1.5 meters for the mainstem of Redwood Creek, and 1 meter for third and fourth order tributaries to Redwood Creek. This target is based principally on the results reported by Flosi and Reynolds (1994). The targets for the mainstem of Redwood Creek are higher than the results reported by Flosi and Reynolds because Redwood Creek is a larger, higher order stream than the stream type referred to in this study. In addition, there is some evidence that chinook salmon prefer deeper pools than coho. The targets are also consistent with the "species habitat needs matrix" developed by an interagency group in connection with resource management discussions with Pacific Lumber company (NMFS, 1997).

b. Existing Conditions and Comparison with Numeric Target

Limited information is available concerning pool depths in Redwood Creek. The Redwood Creek Watershed Analysis (1998) indicated that mean pool depths at three locations in Redwood Creek mainstem in 1986 were about 1.4-1.8 meters. If these results are indicative of pool depths in the mainstem as a whole, it would appear that the > 1.5 meter numeric target is close to being met.

5. Mean Particle Size Diameter (d_{50})

The d_{50} is the median value of the size distribution in a sample. It is a measure of the central tendency of the whole sample, and thus is one of several indicators of how "fine" or "coarse" the sample is overall. As discussed in the discussion for the percent fines targets, both amount and size of fine and coarse sediments can impact salmonid life stages. Various measures of central tendency have been used by researchers (Young, et al. lists several). The d_{50} indicator is selected for Redwood Creek because it is easy to calculate based on results from pebble counts. In a study that evaluated the relationship between hillslope disturbance and various instream indicators, Knopp (1993) found that clear trend of decreasing particle sizes in the riffles was evident with increasing upslope disturbance. Moreover, Knopp found that a statistically significant difference in average and minimum d_{50} values when comparing reaches in undisturbed and less disturbed watersheds with reaches in moderately and highly disturbed watersheds where the stream gradient was less than 4 percent. Therefore, the d_{50} levels identified in undisturbed and less disturbed locations are good candidates for numeric targets for Redwood Creek. Knopp also found that the moderately disturbed reaches were not statistically different from the highly disturbed reaches. This indicates that d_{50} results may take upwards of 40 years before mitigation of current disturbance is positively reflected.

a. Numeric Targets

<u>The targets for d_{50} are means greater than or equal to 69 mm and a minimum of greater than or equal to 50 mm for stream reaches with less than 4 percent gradient.</u> The d_{50} indicator has two targets associated with it. The higher number $\geq$69 mm represents the optimum target, while the lower number $\geq$50 mm represents the minimum number that should be found. By setting two numbers, the State recognizes that there may be annual variability in this target. These values are based on Knopp's findings (1993) concerning d_{50} levels in north coast watersheds which were relatively undisturbed. Because Knopp found the d_{50} to be a discriminating indicator (that is, an indicator capable of distinguishing between watersheds which were more or less disturbed as a result of prior management), the indicator and associated target levels identified in Knopp's study are appropriate.

b. Existing Conditions

Table 6 is a summary of surface d_{50} data collected by USGS and Redwood National and State Parks in 1979 and again in 1994 at 8 monitoring sites along the mainstem of Redwood Creek. It should be noted that these data were collected using a surface pebble count method. This method may not produce reliable results regarding percentages of very fine sediments due to operator variability. In addition, monitoring was conducted at a relatively small number of sites on only 2 occasions. For these reasons, firm conclusions concerning actual past or present conditions for fine sediment in Redwood Creek should not be drawn based on this limited data set. However, the limited data are reported to provide some basis for comparing historical and target conditions.

c. Comparison of Numeric Targets and Existing Conditions

Quantitative comparisons of historical and target conditions are infeasible due to the limitations in the available data. While definitive comparisons cannot be drawn, data set, it appears that d_{50} levels in the watershed do not meet the numeric target to a significant degree, and that mean particle sizes are higher in the middle/upper watershed than in the lower watershed. The numeric target for the mean particle size diameter is set for the watershed as a whole. However, particles tend to become finer as they are transported downstream due to stream power and friction. The targets set for the mean particle size diameter for the lower portion of the watershed may be higher than may be needed for recovery of spawning habitat. As more information becomes available during instream monitoring, the numeric targets for the lower part of the watershed may be adjusted during subsequent TMDL revisions.

6. Large Woody Debris

The removal of vegetation (particularly large conifers) from the riparian zone of the Redwood Creek watershed causes: 1) a loss of stream bank stability and increased stream bank erosion, 2) adverse effects on stream channel morphology, including pool formation, and channel geometry, 3) a loss of sediment filtering capacity and increases in sediment delivery, and 4) a reduction in the potential for large woody debris recruitment to the stream and in the stream's sediment transport efficiency. This statement relates to the COLD beneficial use and the potential for sediment and settleable matter to impact stream channel stability and habitat niches.

a. Numeric Target

The numeric target for large woody debris is improving trends.

b. Existing Conditions and Comparison with Numeric Target

Limited information is available concerning large woody debris within the riparian management zone in Redwood Creek. In a study by Pitlick, 1982, 16 tributaries in Redwood Creek Watershed were evaluated for percentage of sediment stored by large woody debris. Values ranged from a low of 13 percent to a high of 94 percent. On average, greater than 40 percent of the sediment volume was stored by large woody debris.

7. TURBIDITY

A. NUMERIC TARGET

THE NUMERIC TARGET FOR TURBIDITY IS LESS THAN 20% OVER BACKGROUND LEVELS, AS DEFINED BY THE OBJECTIVES OF THE BASIN PLAN.

B. EXISTING CONDITIONS AND COMPARISON WITH NUMERIC TARGET

EXISTING CONDITIONS AND THE TARGET LEVELS WILL BE DEFINED AT SELECTED SITES DURING THE FIRST WINTER FOLLOWING ADOPTION OF THE TMDL.

8. LANDSLIDE FREQUENCY

A. NUMERIC TARGET

THE NUMERIC TARGET FOR LANDSLIDING IS LESS THAN 20% OVER BACKGROUND LEVELS, AS DEFINED BY COMPARISONS OF LANDSLIDE RATES IN TERMS OF VOLUME PER UNIT AREA OF TREATED AND UNDISTURBED (OR 'LESS DISTURBED') HILLSLOPES ON THE SAME GEOLOGIC UNIT. COMPARISONS WILL BE MADE USING ANALYSIS OF AERIAL PHOTOGRAPHS TAKEN AFTER MAJOR (I.E. 5-YEAR OR GREATER RECURRENCE INTERVAL) STORMS.

B. EXISTING CONDITIONS AND COMPARISON WITH NUMERIC TARGET

[TO BE ADDED]

9. HILLSLOPE HYDROLOGIC CHANGE

A. NUMERIC TARGET
THE NUMERIC TARGET FOR HILLSLOPE HYDROLOGIC CHANGE IS DEFINED ON THE BASIS OF THE AVERAGE HYDROLOGIC MATURITY OF VEGETATION IN TRIBUTARY WATERSHEDS. VEGETATION CONDITIONS WILL BE MAINTAINED AT A LEVEL THAT THE FREQUENCY OF FLOODS OF ANY SIZE LARGER THAN A 1-YEAR RECURRENCE INTERVAL FLOW IS INCREASED BY LESS THAN 20% (I.E., A 100-YEAR FLOOD CAN BECOME NO MORE FREQUENT THAN AN 80-YEAR STORM. CALCULATIONS WILL BE MADE USING THE METHOD DESCRIBED IN ATTACHMENT 1.

B. EXISTING CONDITIONS AND COMPARISON WITH NUMERIC TARGET
[TO BE ADDED]

Conclusion

The numeric targets are intended to interpret and apply the narrative water quality objectives. They were developed to support a goal of optimal salmonid success which is a conservative approach. A variety of instream indicators were selected because no single indicator provides a truly effective, discriminating measure of the relationship between sediment loading and instream sediment impacts. The instream numeric targets are expressed as ten year rolling average values to account for interannual variability.

As additional information concerning these indicators becomes available through ongoing monitoring efforts by the State, Redwood National and State Parks, landowners, and other stakeholders, these indicators and targets will be revisited and revised if necessary to provide the most discriminating set of indicators possible. It should be noted that very useful monitoring information is being collected through the parks' ongoing monitoring of monumented cross sections and associated thalweg (low flow channel) profiles. Although it was infeasible to derive specific indicators and numeric target values for these monitoring methods for this TMDL, researchers are currently developing indicators which could serve this purpose in the future. Cross section and thalweg measures should prove effective in the future as indicators of channel stability and change over time. The Regional Water Board will consider inclusion of indicators based on these and other new monitoring approaches as they become available in the future.

It is recognized that no indicators were selected to address the issues of old growth redwood risks in the park or impairment of estuarine habitat near the mouth of Redwood Creek. The Regional Water Board expects that if sediment reductions result in attainment of the numeric targets established in this TMDL, future risks to remaining streamside groves of old growth redwoods and sediment-related estuary impairments will be substantially reduced. However, some of the problems in the estuary apparently are associated with levee structures which the TMDL is not designed to address.

SOURCE ANALYSIS

The purpose of the Source Analysis is to demonstrate that all pollutant sources have been considered, and significant sources estimated, in order to help determine the degree of loading reductions needed to meet numeric targets and the load allocation or loading capacity. 40 CFR 130.2 defines a TMDL as the sum of individual wasteload allocations for point sources, load allocations for non-point sources and natural background. The TMDL must not exceed the loading capacity of the receiving water for the pollutant of concern (in this case, sediment). In order to estimate the loading capacity of Redwood Creek, existing and potential sources must first be characterized. This section provides three types of information:

- an estimate of average annual sediment loads per square mile for the entire Redwood Creek watershed,
- estimates of average annual sediment loads per square mile for three "reference" tributary watersheds within the Redwood Creek watershed, and
- estimates of historical sediment loading rates from all the significant sources of sediment in the Redwood Creek watershed, organized by erosional process categories.

For Redwood Creek, two general types of sediment source information are available from geomorphic research and monitoring programs of the National Park Service and the U.S. Geological Survey. These are: 1) measurements of erosional processes within the watershed, and 2) records of sediment transport in Redwood Creek and some tributaries. The first type of information was used primarily to estimate the relative contributions of different source categories to overall sediment loading. The second type of information was used to estimate overall sediment loading rates for the Redwood Creek watershed and localized loading rates for three tributaries. The overall loading rate information provides the baseline against which TMDL-related sediment reductions are calculated. The localized tributary loading rate information assists in estimating the future loading capacity of Redwood Creek watershed and the overall sediment discharge reductions needed to protect beneficial uses.

Long Term Estimates of Total Sediment Loading

An estimate of long term annual average sediment loading per square mile was determined for the Redwood Creek gauging station at Orick, near the downstream end of the watershed. Data reported in the Redwood Creek Watershed Analysis, supplemented by data furnished by Redwood National and State Parks researchers, were analyzed to develop long term annual average sediment output rates for the period 1954-1997. This is the amount of sediment which actually moves out of the watershed past the Orick gauging station.

During the 1954-1997 period, there was a substantial increase in instream storage of sediment delivered to Redwood Creek and its tributaries. Most of this increase in instream storage was the result of a few major discharge and flood events of which the 1964 flood was most important (NPS, 1998). The sediment budget calculated for the Redwood Creek Watershed Analysis estimates that there was a net increase in the volume of sediments added to instream storage which was on the order of 23% of the total sediment output from the watershed (NPS, 1998). Most of the stored sediments are either in the mainstem of Redwood Creek or at the bottoms of tributary streams. It has been estimated that stored sediments may take several decades to be remobilized, move downstream, and eventually discharge from the watershed. This huge increase in stored sediment in Redwood Creek caused major adverse impacts to the stream channel and to aquatic habitat as a result. The Redwood Creek Watershed Analysis discusses these impacts in detail. The long term restoration of aquatic habitat in Redwood Creek depends, to a significant degree, on the ability of the system to erode and move out these excessive deposits of stored sediment.

For the loading estimates developed for this section, sediment storage was not included as a specific factor in the analysis for several reasons. First, although an estimate of additions to stored sediment is available for the period 1954-1980, no estimate of changes in stored sediment from 1980-1997 is available. Therefore, it was infeasible to calculate a reliable estimate of changes in instream stored sediment for this period. Second, additions to stored sediment have caused significant damage to aquatic habitat in Redwood Creek. If instream storage were added to the loading estimate as a sediment sink, the overall estimate of sediment loading from 1954-1997 would be increased substantially. By including instream storage in the analysis, it could create the impression that continuing increases in instream storage in the future are acceptable. This is not the case; to the contrary, decreases in instream stored sediment are needed. Third, the estimates of sediment reductions needed in the watershed were made through comparisons with "reference" watershed sediment loading rates for three tributary watersheds in Redwood Creek watershed. The Redwood Creek Watershed Analysis indicates that 60-80% of flood-related instream sediment deposits are flushed out of tributary watersheds within 10 years, in contrast to the mainstem. In order to more fairly compare loading rates for the tributary "reference" watersheds and the loading rates for the entire Redwood Creek watershed, it is appropriate to exclude instream storage from the loading estimates for the Redwood Creek mainstem.

This analysis treats instream channel storage of sediment as a potentially long term, but still temporary sink for sediment which is associated with substantial adverse impacts to beneficial uses and which is generally not amenable to control after it has occurred. It is not expected that following the sediment loading reductions called for in the TMDL, there will be significant increases to instream storage except in response to very infrequent, high magnitude events. For these reasons, the simplifying assumption was made that in the long term, sediment inputs equal sediment outputs in properly functioning streams. In other words, the total sediment loading estimate does not separately account for instream storage as a sink or a source of sediment outputs at Orick.

Table 2a provides summaries of annual sediment loading per square mile at Orick based on estimates in the Redwood Creek Watershed Analysis for the periods 1954-1980 and 1974-1992 along with loading estimates calculated for this report for the period 1981-1997 based on sediment loading data provided by Redwood National and State Parks. Table 2a also provides an estimate of annual loading per square mile at Orick for the period 1954-1997 which is used as the baseline for calculating the TMDL. As discussed in Appendix C of the Redwood Creek Watershed Analysis, the 1954-80 estimate is based on actual data collected by U.S. Geological Survey since 1971 along with an estimate of probable sediment yields from 1954-1971 by Knott (USGS, 1981, cited in RNP, 1998a). The 1974-1992 estimate is based on USGS and NPS data collected at Orick and is reported in the Redwood Creek Watershed Analysis. The 1981-1997 estimate is based on USGS and NPS data provided in the Redwood Creek Watershed Analysis.

For the 1981-1997 estimate, where bedload data were not reported, it was assumed that bedload equals 25% of total sediment transport in the Redwood Creek system. This assumption is based on comparison of suspended and bedload sediment loading rates from 1974-1992 and is consistent with the Redwood Creek Watershed Analysis, which reports that bedload accounts for roughly 20-

25% of total sediment load, and with findings of other researchers (e.g. Lisle and Madej, 1992, which reports that bedload constitutes 10-30% of total load).

The 1954-1997 loading estimate was calculated as follows:

$$\frac{[(\text{54-80 av. loading rate}) * (\text{\# of years 54-80}) + (\text{81-97 av. loading rate}) * (\text{\# of years 81-97})]}{(\text{number of years 1954-1997})}$$

which is:

$$\frac{[(5995*27) + (2769*17)]}{44} = 4749 \text{ tons/square mile/year}$$

Estimates of Annual Loading for "Reference" Tributaries

Annual average sediment loads per square mile were calculated for three tributaries of Redwood Creek which are believed to be in relatively good condition in terms of erosion potential and which, as a result, may serve as "reference streams" for purposes of comparing localized erosion rates with erosion rates of the watershed as a whole. They have received relatively little disturbance through timber harvesting, road building, and other land management activities in recent decades when compared to most of Redwood Creek watershed, and are reasonably representative of the major geological formations present in the watershed. This type of comparison assists in evaluating TMDL goals or desired conditions with respect to sediment loading rates and in estimating the watershed's loading capacity for sediment inputs. The first two tributary watersheds may be characterized as moderately vulnerable to erosion due to land management impacts:

> Panther Creek is located on the west side of the valley and was, until recently, relatively undisturbed by intensive logging for many decades. Most of Panther Creek watershed was also harvested several decades ago, although intensive logging has resumed in the last 2 years (personal communication with Greg Bundros, RNP). Panther Creek was selected partly because it is underlain by Redwood Creek schist, the most common rock type west of Redwood Creek.
>
> Lacks Creek is a larger tributary on the east side of the valley which has experienced relatively little timber harvesting in recent decades and now hosts extensive mature second growth forest (personal communication with Greg Bundros, RNP, June 1997). Lacks Creek is underlain by a combination of rock types -- principally the Coherent Unit of Lacks Creek (mostly less erosive sandstones) and the Incoherent Unit of Coyote Creek (more erosive silt and mudstones)-- and is believed to be generally representative of the geology of the east side of the valley.
>
> Little Lost Man Creek is tributary to Prairie Creek, the largest tributary to Redwood Creek, and has experienced no significant logging or land management disturbance. It is underlain by a third major rock type which characterizes the Prairie Creek subwatershed. Little Lost Man Creek (and Prairie Creek as a whole) are not representative of the rest of Redwood Creek watershed because they are less steep, are underlain by a generally less erosive rock type, and are much less intensively managed.

Note that although these three tributary watersheds are appropriate for examination as historical reference watersheds, they are not assumed to be appropriate as future reference streams for comparative analysis. It is quite possible that Panther Creek and Lacks Creek will be subject to intensive future management which may result in unacceptably large increases in loading rates. Additional work would be needed to evaluate whether they are appropriate reference streams for the purpose of comparing future erosion rates with erosion rates for the entire Redwood Creek watershed.

Sediment transport data were collected at gauging stations near the mouths of the three tributaries discussed above: Panther Creek, Lacks Creek, and Little Lost Man Creek. Table 2b presents estimates for annual average loading rates per square mile for each of these locations. Because bedload data were not generally available after 1992, the estimates were based on the assumption that bedload equals 25% of total sediment loads (see above discussion for rationale).

In order to facilitate comparisons between loading rates for these locations and for the Redwood Creek watershed as a whole (as calculated for Orick from 1954-1997), Table 2b also presents adjusted loading rate estimates for each of these locations. The annual average loading rates were adjusted to account for different time periods covered by the data record in each location. The adjustments are based on the assumption that percentage differences in the average annual loading rates for the entire watershed between the 1954-1980 period and the 1981-1997 period also were experienced in the tributary watersheds. It is recognized that this assumption is not well validated; however, it is reasonable to assume that loading rates in the "reference" tributaries and for the watershed as a whole would vary in proportion to each other over time.

For Panther Creek, and Lacks Creek, data were generally available for 1981-1997 (although data for 1989-91 were missing). For Little Lost Man Creek, data were only available for 1993-1997.

For Redwood Creek at Orick, the annual loading rate for 1954-1997 was 172% of the loading rate at the same location from 1981-1997. The adjusted estimated loading rates for Redwood Creek at Okane, Panther Creek, and Lacks Creek are equal to 172% of the estimated 1981-97 loading rates to account for the higher loading rates assumed to have occurred before 1981.

For Little Lost Man Creek, data were only available for 1993-1997. For Redwood Creek at Orick, the annual loading rate for 1954-1997 was 127% of the loading rate at the same location from 1993-1997. The adjusted estimated loading rate for Little Lost Man Creek is equal to 127% of the estimated 1993-97 loading rates to account for the higher loading rates assumed to have occurred before 1993.

Specific Source Estimates

Sediment loading associated with specific sediment source categories was estimated based primarily on analysis of the sediment budget in the Redwood Creek Watershed Analysis (RNP, 1998). A sediment budget quantifies sediment sources (inputs), by each erosional process, as well as changes in the amount of channel stored sediment, and sediment outputs as measured at gauging stations over a designated time frame (Reid and Dunne, 1996). The Redwood Creek sediment budget provides specific estimates of total erosion from all the significant source categories (erosional processes) for the period 1954-1980 along with estimates of instream sediment storage and sediment outputs at Orick. The specific source estimates for this TMDL were calculated by multiplying the percentage of total load associated with each individual source category by the total sediment load estimated above for the period 1954-1997.

This approach assumes that future loading rates from different source categories will be proportional to historical loading rates for these categories. This assumption is reasonable given that the main erosion processes of interest (and their causes) have not changed substantially in the watershed. There continue to be a large number of poorly designed and maintained roads and skid trails in the watershed, and intensive timber harvesting activities continue. What has changed is spatial distribution of these land management activities. Road construction and logging have decreased in the lower watershed and increased in the upper watershed.

Quantifying sediment sources involves determining the volume of sediment delivered to stream channels by the variety of erosional processes operating within the watershed. For the Redwood Creek watershed, these can be divided into two general processes or sediment delivery mechanisms: 1) mass movement (of which landslides are most important) and 2) fluvial erosion (road and skid trail crossing failures, gullies, and surface or sheetwash erosion, and stream bank erosion). Erosional processes in the watershed range from the removal of individual soil particles by raindrops to extensive landslides that cover entire hillslopes. In general, erosion caused by obvious large-scale earth movement has been better documented than erosion caused by dispersed small-scale processes. The smaller-scale processes, however, may also be of great importance in generating sediment because they are more widespread. Past studies indicate that streamside landsliding and fluvial hillslope erosion may be the most important processes delivering sediment to Redwood Creek (Harden and others, 1978; 1995; Kelsey and others, 1981a; 1981b, cited in NPS, 1997). The Redwood Creek Watershed Analysis discusses different erosional processes of interest in Redwood Creek in detail; a brief summary of those processes is presented here.

Landslides

Streamside landslides are clearly an important source of sediment in the Redwood Creek watershed, because of their number and volume, and because they deliver sediment directly to channels. Streamside landslides include debris slides, debris avalanches, and earthflows; however, debris slides account for most of the streamside landslide volume (Kelsey and others, 1995, cited in NPS 1997). Streamside landslides may be caused in part by channel aggradation (Janda and others, 1975, cited in NPS 1997). Sediment deposited in the channel raises water levels during storms, resulting in undercutting of steep hillslopes that subsequently fail as debris slides.

Most streamside landslides identified for the 1954-97 period occurred between 1962 and 1966. Between 1970 and 1976, the number of new streamside landslides decreased in the upper watershed, but increased in the middle and lower watersheds. Few streamside landslides have been initiated during the relatively dry period since 1975, although the 1997 storm activated a substantial number of new slides.

The most aerially extensive mass movement features in the watershed are earthflows; however, they contribute relatively little sediment to Redwood Creek (NPS 1997). Landslides other than streamside landslides include debris avalanches and debris, slumps, forested block slides, and some large and relatively inactive earthflows. These landslides are much less significant as sediment sources than are streamside landslides.

FluvialHillslope Erosion

Fluvial hillslope erosion in the Redwood Creek watershed is apparent in both natural and disturbed settings. On unlogged forested hillslopes, fluvial erosion is related to interactions between subsurface piping through root channels and gully and rill erosion. On logged hillslopes, extensive networks of rills and gullies have developed from streamflow diversions and washouts at road and skid trail stream crossings, from ditches and cutbanks, and from interception of subsurface flow along roads and trails. Surface erosion of logged areas may also have increased as a result of decreased interception of rainfall by the forest canopy following harvest. Prairies are particularly susceptible to gully erosion, and road runoff has carved numerous large gullies in the Bald Hills area, near Berry Summit on Highway 299, and other areas within the watershed. Previous studies have documented large increases in fluvial erosion on lands where timber has been harvested or where roads have been constructed (Janda and others, 1975; Nolan and others, 1976; Walter, 1985; Hagans and Weaver, 1987, cited in RNP, 1998).

Channel storage

Massive amounts of coarse sediment were deposited in tributaries and the upper and middle reaches of the mainstem during the flood of 1964. During subsequent floods, particularly in 1972 and 1975, coarse sediment was scoured from tributaries and the upper mainstem and re-deposited in lower reaches.

Sediment stored within the channel system continues to move in wave-like fashion downstream (Madej and Ozaki, 1996). As of 1990, peak aggradation was about 5 miles downstream from the Tall Trees Grove and about 4 miles upstream of Orick (fig. 3-5). Channel cross section surveys in 1995 indicated that, for the first time since measurements began in 1973, the channel bed between the Tall Trees Grove and Orick was scouring. The sediment wave, therefore, is beginning to attenuate in the lower reach as a result of particle attrition and selective transport. However, it seems clear that sediment discharged into Redwood Creek during major storm runoff events remains in storage for decades or longer. High flow events can remobilize these stored sediments and cause adverse impacts through channel modification and sediment redeposit in downstream habitat areas.

Sediment Budget Adjustments

Sediment budget estimates of tributary streamside landslides were further subdivided for the TMDL in order to reflect different likely causative mechanisms. Pitlick's study of landslide associations with pre-failure site conditions (Redwood National and State Parks, 1982) provides information which can be used to estimate the relationship between landslides and land uses. Pitlick showed that for Redwood Creek tributaries, 40 percent of stream side slope failures in tributary canyons were logging related, and 80 percent of the total landslide volume came from slopes logged prior to failure. Based on Pitlick's analysis, tributary streamside landslides were divided into three categories: natural (corresponding to Pitlick's unlogged category), road- related (corresponding to Pitlick's road-related failures category) and harvest-related (corresponding to Pitlick's clear cut and selection cut categories). Landslides were divided based on the percent of total inventoried slide mass measured by Pitlick for each category. This approach assumes that the distribution of landslide volumes associated with roads, harvesting, and natural conditions for the watershed as a whole is the same as measured in Pitlick's sample of several hundred landslides.

Harvey Kelsey, Mary Ann Madej, and others conducted a study in 1980 of sediment sources and sediment transport in Redwood Creek. Their study of 586 mainstem landslides revealed that approximately 50 % of the slides had one or more associated roads ("Sediment Sources and Sediment Transport in the Redwood Creek Basin: A Progress Report", May 1981, Kelsey, H., et. al). The evaluation of mainstem landslides recognizes that the volume of each slide may be variable. However, the volume of mainstem landslides associated with roads, or other management activities may represent at least 50 percent of the total load.

Table 2c reports the results of the modified sediment budget. Annual average loading rates were estimated by calculating the percentage of the total estimated loads associated with each source mechanism, then multiplying that percentage by the estimated total average annual sediment load for 1954-1997, as reported in Table 2b.

Explanation of Sediment Budget

About 54% of the overall budget was from fluvial and surface erosion, and about 46% of the budget is associated with mass wasting processes. Road-related erosion processes account for approximately 50% of the total budget, including significant proportions of the loadings associated with both fluvial and mass movement processes. It is difficult to estimate the proportion of total loading associated with timber harvesting (road-related impacts aside), but it probably exceeds 10% of the total. Natural background erosion accounts for roughly 30-40% of the total loadings. As discussed above, it is assumed that approximately 10% of average annual sediment loads were stored instream during the period 1954-97.

This sediment budget is expected to be accurate within a factor of about +/- 40%. As such, it should be adequate for purposes of estimating the relative share of loadings from different source categories. Because this TMDL is being established through the phased approach, there will be opportunities in the future to evaluate the accuracy of the sediment budget and associated TMDL loading allocations, and make adjustments as necessary.

Conclusion

For the period 1954-1997, long term average annual sediment production rate for the entire watershed is estimated to be approximately 4750 tons/mi^2/yr. Approximately half was from mass wasting and half from fluvial erosion sources, including surface erosion processes. About half the sediment production was associated with roads and skid trails and roughly 10%-20% was associated with timber harvesting (not including harvest related roads and skid trails). Perhaps 30%-40% of total loads were naturally occurring, or at least were not associated with specific land management causes.

It is important to emphasize that average annual loading rates provide useful information for planning only when a long term monitoring and analysis horizon is applied. Evaluation of sediment loading dynamics over short time periods (e.g., less than 10 or more years) is unlikely to yield reliable results, given that Redwood Creek sediment loading is dominated by infrequent, high magnitude events. For example, the key sediment loading events of the past 40 years were believed to be storms expected to occur perhaps once every 25-50 years. Just as important, stream recovery from high magnitude sediment loading events may take decades or longer to occur.

Although average annual sediment loading rates for the period 1981-97 were substantially lower than the period 1954-1980, it is not clear that the recent lower loading rates indicate that the sediment loading problems in the watershed are a thing of the past. The 1980s and early 1990s were marked by lower than normal precipitation and relatively few high magnitude events. Thus sources on the hillslope could be triggered by future high rainfall/flow events. However, the lower loading rates may be also be attributable, to some extent, to improvements in timber harvest practices. This period coincided with a tightening of California Forest Practice Rules and the use of more protective harvest practices; however the amount of logging in the watershed has not declined during the period since Redwood National and State Parks was established. Rather, logging has been moved upstream into the middle and upper parts of the watershed. Analysis of future loadings from land management practices will be needed to evaluate the degree to which lower loading rates for the 1980-97 period were associated with improvements in forest practices.

The early analysis of the effects of the 1997 "New Year's" storm (approximately an 11 year storm) indicates that a large amount of unaddressed erosion potential remains (NPS 1998). Over 100 large landslides were triggered or reactivated, and multiple road failures occurred both within the Park and on lands outside the park. It was estimated that over 900,000 tons of sediments were discharged into Redwood Creek or its tributaries, or moved into unstable hillslope positions and are perched to fail. The erosion response to this storm indicates that additional action is needed to prevent ongoing, destructive sediment loading in the watershed.

LOADING CAPACITY LINKAGE ANALYSIS

In order to determine the TMDL, it is important to assess the magnitude of instream sediment problems and the associated levels of sediment source reductions needed to address instream problems. The result of this assessment is an estimate of "loading capacity" -- the amount of sediment the Creek can assimilate and still meet its water quality standards. This section assesses the degree to which sediment reductions are needed from sources in the Redwood Creek watershed to alleviate the instream sediment problems discussed in the Problem Statement section and quantified in the Numeric Targets section. The analysis is based on two methods of comparing existing and desired conditions for the watershed:

1. quantitative comparison of average sediment loading rates per square mile in more highly impacted and relatively unimpaired areas of Redwood Creek watershed, and
2. qualitative comparison of existing and historical conditions with target levels for the instream indicators selected in the numeric targets section.

It is recognized that inferring linkages between prospective hillslope erosion sources and instream impacts based on these methods will produce uncertain results. However, it is necessary to estimate the level of sediment reductions needed in the future to meet water quality standards. Because there are no reliable direct linkages to evaluate (i.e., the sediment-impact relationships tend to be separated in time and space) and no reliable methods for modeling those linkages, it is necessary to rely on these less certain inferential methods. The Regional Water Board believes that through future monitoring and evaluation, it will prove more feasible to evaluate these cause-effect linkages with greater certainty than was feasible for this TMDL.

Comparison of Sediment Loads in Redwood Creek to Reference Streams

As discussed in the preceding sections, Lacks Creek, Panther Creek, and Little Lost Man Creek provide the best local candidates for estimating historical reference watershed loading rates. Adjusted average annual loading rates were estimated for each of these tributaries (see Source Analysis chapter for details), and the results are reported along with the average annual loading rates estimated for Redwood Creek at Orick.

To allow a comparison of historical loading rates for the Redwood Creek watershed as a whole with "reference watershed" loading rates, it was necessary to weight the loading rates for the reference watersheds in accordance with how representative their underlying geologies are of the entire watershed. For this adjustment, it was assumed that Panther Creek loading rates would be representative of "reference" loading rates for all of the watershed area underlain by schist-- about 42% of the watershed. It was further assumed that Little Lost Man Creek loading rates were representative of "reference" loading rates for the Prairie Creek area-- about 14% of the watershed. Finally, it was assumed that Lacks Creek loading rates were representative of "reference" loading rates for the remainder of the watershed-- about 44% of the watershed. The Lacks Creek assumption is reasonable because that tributary is underlain by both of the most common remaining geologic types present in the watershed, a combination of resistant sandstones and less resistant mudstones and siltstones.

The weightings were calculated as follows to yield a single estimated reference loading rate for the entire Redwood Creek watershed. First the sediment loading rates for each reference stream (column b) were multiplied by the corresponding percentage (expressed as a decimal, i.e., 42% becomes 0.42) of the whole watershed underlain by the reference stream geologic type (column c) to yield loading rate factors for each reference. The three loading rate factors were added together to yield the overall estimated loading for the entire watershed. The weighting of the "reference" loadings yields an overall composite estimate of loadings associated with reasonably well functioning watersheds which are not experiencing excessive human-caused erosion as shown in Table 2d. This calculation yields an estimate for a watershed- wide reference loading rate of 1960 tons/square mile, which is 59% lower than the estimated watershed loading rate for 1954-1997 of 4750 tons/square mile. While considering the assumptions made on calculating the reference loading rate, the result suggests that a reduction of approximately 60% might be needed in order to achieve "reference watershed" conditions over a long time horizon.

Although some land management activity was occurring in Panther Creek and Lacks Creek several decades ago, this average annual loading estimate (1960 t/sq mi/yr) based upon reference streams is considered conservative because it includes the use of Little Lost Man Creek- a nearly pristine tributary -- as a reference stream for 14% of the watershed. It may not be necessary to attain the near pristine levels of sediment loading associated with Little Lost Man Creek in order to restore a functioning aquatic habitat in the watershed as a whole.

Qualitative Analysis of Instream and Hillslope Conditions

Linkages between sediment sources in the watershed and instream conditions are generally indirect and highly variable. However, over the long term, reductions in sediment inputs to the stream system are expected to result in reduction in sediment distributions in the channel. Over time, the instream indicators identified in the Numeric Targets section should reflect changes in response to reduced sediment loading and transport. Because of historical data limitations, it was infeasible to prepare a quantitative comparison between historical and target conditions for instream indicators. However, Table 1a summarizes the qualitative comparisons reported in the Numeric Targets section. This qualitative comparison appears to indicate that instream conditions remain inadequate to support healthy habitat, but that conditions may be improving. Significant continued sediment loading reductions appear to be necessary to address the instream problems associated with sediment. Large storm events of the magnitude seen prior to 1980 have not occurred since. When such events occur, higher sediment loading rates may result and consequently reveal deterioration of instream target conditions.

Conclusion: Estimate of Sediment Loading Capacity in Redwood Creek

The two approaches to inferring sediment load reductions needed to meet water quality standards yield somewhat different results. The reference stream approach indicates that reductions on the order of approximately 60% would be needed. The instream indicator approach indicates that additional unquantified reductions may be needed, but that conditions may actually be improving in many parts of the mainstem creek. In the judgment of the Regional Water Board, these estimates indicate that reductions of about 60% are needed in order for Redwood Creek to meet water quality standards for sediment in the future. This suggests that allowable loading capacity is on the order of 40% of historical loading rates. This figure also compares with the estimation from the sediment budget (Table 2c) that natural background erosion accounts for roughly 30-40% of the total estimated load for the period 1954-1997. By multiplying the historical average annual loading rate (4750 tons/square mile) by the 40% allowable annual loadings, it yields an overall loading capacity estimate at Orick of 1900 tons/square mile/year .

The Loading Capacity meets the regulatory definition at 40 CFR 130.2(f) which states that the loading capacity is "the greatest amount of loading that a water can receive without violating water quality standards."

TOTAL MAXIMUM "DAILY" LOADS AND LOAD ALLOCATION

The requirements of a TMDL are described in 40 CFR 130.2 and 130.7 and Section 303(d) of the Clean Water Act, as well as in various guidance documents. A TMDL is defined as the sum of the individual wasteload allocations for point sources, and load allocations for nonpoint sources and natural background pollutants, such that the loading capacity of the receiving water is not exceeded. There are no point sources in the watershed; nor are any expected to be proposed in the near future. Therefore, the wasteload allocation for points sources is zero. The allocations indicate the amount of pollutant reduction that is required to attain water quality objectives. Allocations may be assigned based on land use, land area, or erosional process. In addition, the regulations at 40 CFR 130.2(g) state that "Load allocations are best estimates of the loading, which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading."

Total Maximum Daily Load Calculation

The TMDL for Redwood Creek is being expressed as long term annual average sediment loading per square mile, as applied at the Orick gauging station at the downstream end of the watershed. This meets the regulatory definition that "TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure" (40 CFR 130.2). This annual TMDL could be converted into daily loads, but expressing the TMDL as an annual average yield better reflects the dynamic nature of sediment movement throughout a watershed over time. The annual average loading rate for this TMDL will be measured in terms of 10 year rolling annual averages. The longer term annual average timestep is an appropriate approach to account for the large interannual variability in sediment loading and the long term timeframe in which beneficial use impacts occur and change. This annual average loading per square mile will be referred to as the TMDL for Redwood Creek. The TMDL is calculated by applying the loading capacity range from the previous section, which was estimated at 1900 tons/square mile/year (rounded). The TMDL for Redwood Creek is therefore estimated to be 1900 tons/square mile/year, expressed as 10 year rolling annual averages.

Explanation of the Load Allocation

The Redwood Creek load allocation for this phased TMDL that is assigned to all landowners is a standard of no controllable discharges of sediment from all non-point sources. The Redwood Creek load allocation has been developed as a long term annual average load per square mile at the watershed-wide scale. Controllable discharges are those discharges resulting from human activities that can influence the quality of the waters of the State and that can be reasonably controlled by prevention or mitigation. It is expected that if all controllable discharges are prevented and corrected, it will result in comparable sediment loading rates as calculated for the reference streams, where sediment loading represents 40 percent of the historic average annual load/square mile for the Redwood Creek watershed. This overall reduction of 60 percent of the sediment load will achieve the loading capacity, and is expected to result in the attainment of the numeric targets. Thus, the Load Allocations meet the regulatory requirements at 40 CFR 130.2(g) in that they are "best estimates of the loading, which may range from reasonably accurate estimates to gross allotments...".

Since a reduction in the average annual sediment load to the Redwood Creek watershed is judged to best occur through the control of management-related sources of sediment that can reasonably be expected to respond to mitigation, altered land management, or restoration, landowners must first identify those sources on a site-specific basis. Table 3 includes a schedule for landowners to inventory the human-caused Sediment Delivery Sites, including unstable areas and riparian areas on their property, and reduce the inventory of sites according to a specific schedule contained in Table 3. These assessments will provide the property-specific data necessary to control sediment delivery from existing erosion sites and future land management measures. Landowners are then directed to implement protective land management measures in accordance with the schedule contained in Table 3 and further elaborated in the Redwood Creek Watershed Erosion Control Plans of the Implementation Plan section of the TMDL. Other landowner responsibilities are also described in the Implementation Plan of the TMDL.

In Table 3, erosion control activities are divided among key source categories. The key source categories are from the adjusted sediment budget presented in Table 2c and discussed in the source analysis section, which was based primarily on the sediment budget in the Redwood Creek Watershed Analysis. Control measures for addressing each of the key source categories are not expected to be 100 percent effective. The percentages reflect professional judgment of how successful the various best management practices (BMPs) generally are in controlling these sources. The application of reasonable practices to control and prevent future loading is expected to result in reductions adequate to meet the TMDL.

Estimates of the percent effectiveness of control measures for addressing loads for road-related sources are derived from field work in the watershed and nearby watersheds by Weaver and Hagans (see, e.g., Weaver and Hagans, 1994).

Estimates of the percent effectiveness of control measures for addressing loads from bare ground were derived from a conservative reading of results of bare ground sediment control practices in Redwood Creek watershed documented in Kveton, et al. and Hagans, et al. (1986).

Estimates of the percent effectiveness of control measures for addressing streambank erosion were based on staff judgment summarized as follows: A significant portion of bank erosion is believed to be associated with higher flow elevations caused by changes in channel shape, which in turn are associated with sediment loads which exceed the stream's natural transport capacity (Rosgen, 1996). As sediment loading is reduced in the future, it is assumed that the frequency and magnitude of bank erosion will decline, and that the volume of eroded bank sediments will decline as well. In addition, it is expected that some streambank erosion will be addressed through stream restoration projects in some parts of the watershed. Finally, it is expected that some reduction in bank erosion will occur in response to improvements in livestock management practices and, potentially, timber harvesting practices in riparian zones.

Estimates of the percent effectiveness of control measures for addressing harvest related mass wasting are based on staff judgment and experience, and are consistent with control rates estimated for the Garcia River sediment TMDL.

The available analysis concerning associations between landslides and roaded, harvested, or unlogged areas focused upon landslides in tributaries (Pitlick, 1982). Because the patterns and causes, and associated ability to prevent landslides along the mainstem of Redwood Creek are not well understood, this analysis assumed that mainstem landslides would not be as amenable to control as tributary landslides. Following this reasoning, it is estimated that about 40% of loads from mainstem landslides could be prevented, about half the amount of load prevention which could be expected for tributary landslides which are road related.

The sediment budget description inferred that most debris torrents are road-related. Because road-related debris torrents can usually be avoided through proper road siting and maintenance (e.g., through avoidance of side-casting), the estimated 50% effectiveness of control measures is realistic.

The allocation of responsibility for road-related sediment applies to all land use activities including roads for timber, agricultural, residential, and park management activities as well as state and county roads. The sediment budget prepared by Redwood National and State Parks does not separately estimate erosion associated with agriculture, although the existing categories account for agriculture related erosion to some degree. Overall, this approach is acceptable because agriculture-related erosion is not believed to be a significant source in Redwood Creek watershed.

Conclusion

The Loading Capacity and Load Allocation were developed in consideration of all major sources of sediment in Redwood Creek. The Redwood Creek load allocation for this phased TMDL that is assigned to all landowners is a standard of no controllable discharges of sediment from all non-point sources, developed as a long term annual average load per square mile at the watershed-wide scale. It is expected that if all controllable discharges are prevented and corrected, it will result in a reduction in the rate of sediment delivery to the watershed overall and achieve the loading capacity which is estimated to be 1900 tons/mi^2/yr, expressed as 10 year rolling annual averages.

MARGIN OF SAFETY, SEASONAL VARIATIONS, LINKAGES AND CRITICAL CONDITIONS

Section 303(d) of the Clean Water Act and the regulations at 40 CFR 130.7 require that TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality. The margin of safety can either be incorporated into conservative assumptions used to develop the TMDL or added as a separate component of the TMDL (EPA, 1991). In every one of the components used to develop the TMDL, assumptions were made where sufficient data were lacking. Conservative assumptions were made in each case as a way of addressing uncertainty associated with the data; this constitutes an implicit margin of safety.

In Redwood Creek, there is inherent annual and seasonal variation in the delivery of sediment to stream systems and in the impacts sediment has on aquatic species during different life stages. However, sediment impacts often occur for periods long after the sediment loading to the stream, and in locations far removed from the loading site. It is technically infeasible to vary the TMDL to account for temporal and spatial variations in sediment loadings and impacts. Instead, the TMDL is designed to account for long term erosion patterns and instream impacts associated with sediment in Redwood Creek by using longer time frames for implementation and evaluation. Furthermore, allocations are designed to apply to the sources of sediment, themselves, not the movement of sediment across the landscape.

The RWQCB has identified these conservative assumptions more specifically to fully account for the implicit margin of safety.

Conclusion

As Table 7 points out, there are a number of uncertainties associated with the supporting documentation, most notably in the source analysis and linkage analysis to estimate loading capacity. Given these uncertainties, conservative assumptions have been made regarding the amount of loading reductions that are needed to attain water quality objectives . This approach is warranted and meets the statutory requirements that a margin of safety take into account any lack of knowledge concerning the relationship between the effluent limitations and water quality.

Collection of site-specific data in the future will help to reduce the uncertainty associated with the current assessment and will therefore allow for a reduction in the degree of conservatism associated with the current assumptions. Thus, it is possible, depending on the quality and quantity of the site-specific data which is collected over time, that adjustments to the TMDL in the future will result in less stringent allocations as the margin of safety is reduced.

SEASONAL VARIATION

There is inherent annual and seasonal variation in the delivery of sediment to stream systems. Surface erosion occurs on an annual basis, but primarily as a result of winter rains. Fluvial erosion and mass wasting, on the other hand, occur as a result of big storms and thus may not be significantly active processes every year. For this reason, the allocations are designed to apply to the sources of sediment, themselves, not the movement of sediment across the landscape or delivery of sediment directly to the stream channel. If implemented as envisioned, potential and existing sediment delivery sites will be identified and the quantity of sediment associated with each site measured or estimated. Then, as a result of mitigation or altered land management, the amount of potential sediment saved from delivery to a water of the State will be measured or estimated. The relationship between the original measurement or estimate of potential sediment delivery and the amount saved by mitigation will indicate the degree to which reductions have been made to achieve the loading capacity of the watershed.

It is difficult to accurately predict specific impacts of sediment loading at particular times and places on particular salmonid life stages given spatial and temporal lag time between sediment delivery and the occurrence of sediment related impacts on beneficial uses. In addition, it is infeasible to predict or control sources at fine spatial and temporal scales in many cases. Therefore, the approach in this TMDL is to select indicators to interpret narrative water quality objectives which are believed to provide a good composite picture of instream sediment-related conditions and changes over time. Then, targets and associated TMDLs are set at levels believed to be protective of beneficial uses at key life stages taking into account the lag time effects. In addition, the numeric targets generally represent summer flow conditions. This TMDL accounts for seasonal variation through the careful articulation of likely cause and effect relationships between sediment loadings and effects on salmonid habitat at different key life stages, and its consideration of lag time effects.

Normal winter rains and larger storms will nonetheless have an effect on the effectiveness of land management prevention and mitigation measures. Storm events which occur after mitigations have been achieved will provide a test of the success of the mitigation. For this reason, the monitoring plan will propose follow-up inventories of hillslope sources which will help assess post-mitigation success.

CRITICAL CONDITIONS

The regulations at 40 CFR 130.7 state that TMDLs shall take into account critical conditions for stream flow, loading and water quality parameters. This TMDL does not explicitly estimate critical flow conditions for several reasons. First, unlike many pollutants (e.g. acutely toxic chemicals) sediment impacts on beneficial uses may occur long after sediment is discharged, often at locations far downstream from the point of discharge. Second, sediment impacts are rarely correlated closely with flow over short time periods. Third, it is impractical to accurately measure sediment loading, transport, and short term effects during high magnitude flow events which usually produce most sediment loading and channel modification in systems such as Redwood Creek. Therefore, the approach used in this TMDL to account for critical conditions is to use indicators which are reflective of the net long term effects of sediment loading, transport, deposition, and associated receiving water flows. These indicators may be effectively measured at lower flow conditions at roughly annual intervals. Inclusion of a large margin of safety helps to ensure that the TMDL will result in beneficial use protection during and after critical flow periods associated with maximum sedimentation events.

Critical conditions concerning stream habitat status and recovery may change substantially following major storms (e.g., storms with a recurrence interval of approximately 50 years or more). Such storms and the associated floods and huge sediment loads can have the effect of "recallibrating" the stream channel morphology for decades to follow. It may be appropriate to reconsider the TMDL following such an event.

IMPLEMENTATION

As described in the discussion of the Nonpoint Source Management Plan (1988) in the Introduction section of the Strategy, the Regional Water Board is constrained by the Porter-Cologne Act from specifying the manner of compliance with water quality standards. This Strategy is an adjunct to the water quality standards and will be proposed for inclusion in the Basin Plan. Two methods, however, are identified in the Nonpoint Source Management Plan (1988) by which the Regional Water Boards can use their regulatory authorities to encourage implementation of conservation measures. One is to waive adoption of waste discharge requirements on condition that the dischargers implement conservation practices. A corollary to this method is to waive applicability of discharge prohibitions on the same condition as described above. The second method is to enter into a Management Agency Agreement (MAA) with another agency which has authority to require implementation of conservation measures.

Both of these methods are included in the Implementation Plan. The Regional Water Board has already entered into an MAA with the California Department of Forestry and Fire Protection (CDF). Through the MAA, CDF approves timber harvest plans (THP) only after considering the impacts on water quality. With the adoption of the Strategy as an amendment to the Basin Plan, the requirements therein will be considered by CDF prior to their approval of individual THPs, Sustained Yield Plans, and other relevant enforceable timber-related planning documents.

Similarly, the Basin Plan already includes two prohibitions against discharges associated with logging, construction and other related activities. In order to encourage voluntary efforts to develop and implement Erosion Control Plans, the Regional Water Board will not enforce the existing prohibitions for logging, construction, and associated activities against landowners who are implementing an approved Erosion Control Plans. If significant discharges or placement of sediment occurs despite the implementation of an approved erosion control plan, the Regional Water Board will consider the need for revision of the erosion control plan, and will address the discharge or placement of sediment through the issuance of a Cleanup and Abatement Order, if necessary, but will not enforce the violations of the prohibitions.

Further, the application to land management activities in the Redwood Creek watershed of the prohibitions now contained in the Basin Plan will be clarified and expanded. In particular, given the watershed's impaired status, any measurable discharge of sediment shall be considered deleterious to beneficial uses and the prohibition will be expanded to apply to all land uses and all waters of the State within the watershed. The clarification for the prohibitions, as applied in the Redwood Creek watershed reads as follows:

> 1) The controllable discharge or deposition of quantities of soil, silt, bark, slash, sawdust, or other earthen or organic material, other than large woody debris from any logging, construction, gravel mining, agricultural, grazing, or other activity of whatever nature into waters of the state within the Redwood Creek watershed is prohibited.
>
> Controllable discharges or depositions are those discharges or depositions resulting from human activities that can influence the quality of the waters of the State and that can be reasonably controlled by prevention or mitigation.

Again, violations of the prohibitions will not be enforced against any landowner who is implementing an approved erosion control plan.

All landowners engaged in land management activities which result in the discharge of sediment to the stream are encouraged to collect the necessary baseline information, mitigate or control existing and potential sediment delivery sites, and implement fish-friendly land management practices. However, most important to the success of this Strategy is the cooperation and involvement of the largest landowners in the watershed. Without the cooperation and participation of these larger landowners, the overall success of the Strategy and improvements to the instream environment will be significantly lessened.

What has been described above are the implementation options available to landowners who engage in land management activities which cause a discharge of sediment to the stream system. For those landowners who do not engage in activities which discharge sediment to the stream, no additional requirements apply.

Erosion Control Plans

The Erosion Control Plans endeavor to identify a rational framework for reducing sedimentation and meeting the water quality standards for the watershed. Within this framework, however, landowners are given flexibility in how they go about achieving the sedimentation reduction goals and requirements. The Erosion Control Plan is the mechanism by which landowners are encouraged to exercise this flexibility.

Landowners are encouraged and required by others besides the Regional Water Board to develop land management plans for a variety of purposes. For example, the Natural Resource Conservation Service encourages the development of Conservation Plans. The California Department of Forestry and Fire Protection (CDF) encourages the development of Non-Industrial Timber Management Plans and Sustained Yield Plans. The National Marine Fisheries Service encourages the development of Habitat Conservation Plans. The Range Management Advisory Committee encourages the development of Ranch Management Plans.

Because of the overlap in goals among each of these types of plans with the proposed Erosion Control Plan, the Regional Water Board encourages landowners to use their other land management plans as the basis for their Erosion Control Plans, as appropriate. The implementation plan section contains a list of elements the Regional Water Board would like to see in an Erosion Control Plan. If a landowner has developed a land management plan for another purpose which includes most of the elements described in the implementation plan section, a simple amendment-- or letter-- may be sufficient to add any of the remaining missing elements. In short, the Regional Water Board is interested in reducing, as best as possible, the amount of duplication which landowners are sometime required to engage in.

The Erosion Control Plan must be submitted to the Regional Water Board for review and approval by the Executive Officer. Approval will be granted for Erosion Control Plans which reasonably demonstrate a level of water quality protection which is roughly equivalent to that expected from the measures set forth in the Guidelines described in the Implementation Section of the TMDL. If a landowner determines that one or more of the applicable measures in the Guidelines are not feasible in specific areas of his/her ownership for economic or other reasons, the landowner may submit as an Erosion Control Plans the proposal to implement alternative measures in those areas, in conjunction with implementing the remaining applicable measures from the Guidelines. Should a landowner opt to submit as a Erosion Control Plans a land management plan which was developed for another purpose, s/he is welcome to omit any portion of the original plan which they do not think is relevant to the erosion control plan and which they do not care to share with the Regional Water Board as a public agency. Further, a landowner need not wait for a Non-Industrial Timber Management Plan, for example, to be approved by CDF before submitting it to the Regional Water Board as a Erosion Control Plans. The Regional Water Board will review any plan submitted as a Erosion Control Plans on its own merits as an erosion control plan, regardless of its status in another regulatory arena.

Elements of an Erosion Control Plan

The list of elements described below are offered as a means of guiding landowners through the thought process the Regional Water Board believes is necessary for consideration of all the issues of concern. As above, the Erosion Control Plans need not, however, be specifically designed for this purpose alone, if it can simultaneously serve many purposes. As such, the Regional Water Board does not require that an Erosion Control Plans be submitted with these elements in this particular order-- or as distinct, separate elements, as laid out here. As long as the plans contain the following information, landowners are encouraged to submit their Erosion Control Plans in any format and in any order which best suits their own purposes.

1. A section describing the property or properties in question and the predominant land uses and existing land management activities associated with the property(s). Landowners are encouraged, where feasible, to develop consortia with neighbors to share knowledge, skills, and financing. In such a case, a single Erosion Control Plan will suffice.

2. A section describing the methods by which a baseline data inventory of existing and potential sediment delivery sites will be developed. Existing and potential sediment delivery sites are human-caused sites associated with roads, landings, skid trails, and agricultural operations from which sediment is eroding or is likely to erode into a water of the State. Culverts, inside ditches, gullies associated with watering troughs, etc. are examples of such sites. Only controllable sites must be prioritized and mitigated. Controllable sites are those which are human caused and will respond to mitigation, restoration or altered land management practices to prevent sediment discharges.

   The initial inventory of existing and potential sediment delivery sites will serve as the baseline from which to measure (or estimate) the reduction of sediment delivery achieved over time. As such, it must be as thorough and a accurate as feasible. It must be submitted by January 1, 2003, and revised every ten years thereafter.

3. A section describing the means by which controllable existing and potential sediment delivery sites will be prioritized for mitigation or control. Sites associated with roads, skid trails, silvicultural, and agricultural activities in the riparian zone should receive high priority because of the higher Sediment Delivery Reduction Requirements associated with these locations on the landscape. Similarly, sites with the potential to impact important refuge streams should receive high priority. This section must be submitted by January 1, 2003.

4. A section describing the methods by which an assessment will be conducted of unstable and sensitive areas. Unstable areas relevant to timber harvesting are primarily those with the potential for landsliding (e.g., active and potentially active landslides, inner gorges, headwall swales, etc.). Unstable areas relevant to agricultural activities are primarily active and potentially active gullies and stream bank failures. Sensitive areas include the riparian zone and those features which provide essential ecological functions such as: stream bank protection, filtering of eroded material prior to its entering the stream channel, and recruitment of large woody debris.

   The initial assessment of unstable and sensitive areas will serve as the basis for identifying those areas requiring altered land management so as to reduce the potential for human-caused erosion and sediment delivery. As such, it must be as thorough and accurate as feasible. It must be submitted by January 1, 2003.

5. A section describing the land management practices which will be implemented to reduce the future potential for sediment delivery from roads, landings, skid trails, silvicultural operations, agricultural operations, and unstable and sensitive areas. Appropriate land management practices are those practices (including avoidance) which prevent or significantly reduce the acceleration of natural rates of erosion. For example, land management practices in the riparian zone must be designed to ensure that the riparian zone is capable of providing its essential ecological functions, including stream bank protection, filtering of eroded material prior to its entering the stream channel, and recruitment of large woody debris. The discussion of land management practices must include practices for:

   - Road construction, reconstruction, maintenance and obliteration, including measures for designing and installing stream crossings. (This information must be included in a long-term road plan to be submitted to the Regional Water Board by January 1, 2003);
   - Operations in unstable areas, particularly active or potentially active landslides, headwall swales, inner gorges, and active or potentially active gullies;
   - Use of existing skid trails and construction of new skid trails (where applicable);
   - Agricultural practices on the hillslope (where applicable);
   - Wet-weather operational practices;
   - Stream bank protection;
   - Riparian zone filtering; and
   - Large woody debris recruitment.
     CLASS III NO CUT BUFFERS

6. A section describing the monitoring protocols used to monitor the effectiveness of sediment control efforts associated with roads, landings, skid trails, and any other land management activities, structures or facilities identified to be associated with sediment delivery. Where instream monitoring points are established, the landowner is encouraged to describe the monitoring protocols, locations, sampling frequency, and quality assurance/quality control procedures associated with instream, riparian area, hillslope, and sediment delivery reduction monitoring.

7. An optional section describing past or planned restoration projects associated with sediment source control and aquatic habitat improvement, considering the protection of refuge

streams as a first priority, potentially functional fish-bearing streams as a second priority, and nonfunctioning streams as a last priority (Weaver and Hagans 1996).

Rationale for Elements Developed for the Erosion Control Plans for Redwood Creek Watershed

Each of the specific conservation measures described in the Erosion Control Plans for the Redwood Creek watershed were developed by Regional Water Board staff from a number of sources including published literature, other conservation plans, existing regulation, field experience and professional judgment. The rationale for each measure is described below.

Baseline Data Inventory

One of the primary goals of the Erosion Control Plan for the Redwood Creek Watershed is to describe a system which encourages the achievement of sediment source control in an efficient and cost effective manner. Towards this end, the Erosion Control Plan describes the minimum criteria by which sediment delivery sources should be identified and inventoried across an ownership. An important component of the inventory is a system which prioritizes the physical control of sediment sources. Priority for corrective work should be based on beneficial uses of water, volume of sediment at each location, the potential delivery ratio of identified sediment, and whether the site will respond to mitigation. This technique will allow landowners to focus resources on those sites with the greatest potential to deliver sediment to watercourses. The Erosion Control Plan describes the development of a baseline data inventory of potential and existing sediment delivery sites as well as an assessment of unstable areas, including, but not limited to, areas prone to landsliding, gullying, and stream bank failure.

The baseline data inventory of potential and existing sediment delivery sites includes the identification of human-caused sources of sediment from areas where land management activities such as road, landing, skid trail, agricultural facility and watercourse crossing construction have disturbed the natural hillslope or stream channel. These management activities can alter the natural drainage pattern and/or place or expose significant volumes of soil in positions where sediment delivery is accelerated beyond naturally occurring background rates. These areas include both used and unused roads, landings, skid trails and agricultural facilities and other areas where controllable sources of sediment are present.

It is not the intent of Regional Water Board staff that the inventory include the location of every skid trail and abandoned road. Rather the inventory must include only those potential and existing sources of sediment which are human-caused, with justification for those which the landowner has determined will not respond to mitigation, restoration or altered land management. Only controllable sources need be prioritized for mitigation, restoration, or altered land management. Controllable sources are those which are human-caused and will respond to mitigation, restoration or altered land management. The inventory requires a field level evaluation of the ownership.

Sediment Delivery Reduction from Known Sites

The second part of the Erosion Control Plan includes the sediment source reduction schedule. The sediment source reduction schedule is an important corollary to the road inventory because it identifies the reduction of sediment sources within a time line that allows the attainment of the numeric targets. The schedule identifies the annual removal or percent stabilization by volume of the controllable sources identified in the original baseline inventory. This schedule was developed to provide for a one hundred percent (100%) reduction in the controllable, inventoried sources of sediment over a ten year rolling period. The property (e.g., road system, skid trails, landings and agricultural-related sites, as appropriate) will be re-inventoried every ten years prior to the year 2043 for final sediment delivery reduction. It is Regional Water Board staff's belief that re-inventory of the property is necessary to document and identify sediment sources created, exposed or otherwise identified after the completion of the original source inventory. Recurring inventories will also aid in the identification of land management practices that are or are not preventing the creation of additional sediment delivery sources.

The Erosion Control Plans for Redwood Creek watershed includes measures appropriate for a wide variety of land uses. Nonetheless, it strongly focuses on the mitigation and control of existing and potential sediment delivery sites associated with roads. The rationale for focusing on road related sediment is based on the sediment budget for Redwood National and State Parks and a number of published studies which identify roads and related features as a primary source of sediment discharge, such as The Critical Sites Erosion Study (CSES): A Cooperative Investigation by the California Department of Forestry and the United States Forest Service, May 1989. The sediment budget for Redwood National and State Parks indicates that road-related erosion processes account for approximately 50 percent of the total budget. The Critical Sites Erosion Study (CSES) found that "(r)oads and landings were responsible for a disproportionately high percentage of the erosion" observed over the course of the investigation. It was determined that while only four percent (4%) of the study areas was covered by roads, seventy-six percent (76%) of the measured erosion was related to roads or landings.

Reduction of one hundred percent (100%) of controllable sources is required since these are the sites likely to respond well to mitigation, restoration or altered land management. Potential and existing sediment delivery sites will likely be identified which are human caused but will not respond to mitigation, restoration or altered land management. These sites are not considered controllable and need not be prioritized and mitigated.

Assessment of Unstable Areas

The third part of the Erosion Control Plans for Redwood Creek watershed describes the assessment of unstable areas across an ownership. The unstable areas primarily relevant to timber harvesting include active shallow and deep seated landslides, debris slides and flows, earthflows, inner gorges and areas with unstable soils. The unstable areas relevant to agricultural operations primarily include active and potentially active gullies and active and potentially active stream bank erosion. The intent of the assessment of unstable areas is to identify those locations on the landscape which have a high risk of accelerated sediment delivery. It is in these areas that land management activities should be avoided or the practices modified to reflect the sensitivity of the landscape to erosion. Unstable areas are generally features which do not currently involve the alteration of natural surface drainage patterns and/or significant soil disturbance, but have a high potential for accelerated sediment delivery. The unstable areas identified in the assessment are those features that originate on hillslopes (or stream banks) and are not related to road, crossing, landing or skid trail construction.

The Guidelines for the Erosion Control Plans require reductions in mainstem landslides in tributary landslides resulting from management activities on timber harvest units and debris torrents be achieved by the Year 2043. The percent effectiveness of land managment measures to achieve sediment reduction is estimated at 50 percent for Tributary Landslides: Timber Harvest Related;

and Debris Torrents: Silviculture and Road Related. Attainment of this sediment reduction from mass wasting events will be evaluated by inventorying additional (new) features over the life of the Strategy.

The Guidelines section of the Erosion Control Plans for the Redwood Creek watershed include a management practice designed to decrease the potential for timber harvest operations to accelerate mass wasting events (landslides). This measure requires the retention of at least fifty percent (50%) of the existing basal area formed by tree species on unstable areas. This measure was developed from a recommendation made by Dr. Ray Rice at a Board of Forestry sponsored workshop on mass wasting. The measure is designed to allow land use activities on unstable areas while minimizing the potential for the activities to destabilize the feature. By maintaining an adequate number and/or size of trees, tree roots will continue to provide soil stability and evapotranspiration capacity. It will also ensure that tree canopy remains to moderate rainfall intensity directly onto unstable areas. In addition, the placement of roads, landings, skid trails, and concentrated water flow and the implementation of agricultural activities in unstable areas is restricted by the Guidelines for the Erosion Control Plan.

<u>Sediment Delivery Reduction from Unstable Areas</u>

Several management practices are contained in the Guidelines for the Erosion Control Plans to prevent sediment delivery to watercourses from land management activities on unstable areas within the Redwood Creek watershed. One of the practices is related to land management activities which result in significant earth movement, such as road, landing and skid trail construction and reconstruction activities on or adjacent to unstable areas. The remaining measures address other land management activities, such as timber harvest and agricultural operations which do not intentionally result in substantial earth movement.

Because of the inherently unstable nature of the Redwood Creek watershed, Regional Water Board staff recognizes that complete avoidance of unstable areas would be difficult, if not impossible, to achieve while conducting land management activities in the watershed. To decrease the potential for the creation of future sediment delivery sources from roads, landings and skid trails construction across these features, the Guidelines for the Erosion Control Plans require the review and development of site specific mitigation measures by a California Certified Engineering Geologist or Registered Engineering Geologist when road, landing or skid trail construction is proposed across an unstable area. A report prepared by a California Certified Engineering Geologist or Registered Engineering Geologist who developed the site specific mitigation measures is to be submitted to the Executive Officer prior to construction or reconstruction across unstable areas.

The design and installation of proper road drainage is an important component of land management activities, especially in active or potentially active unstable areas. Road construction and reconstruction activities which conform to the guidance contained in the Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994) will prevent the concentration of runoff from road and other disturbed surfaces across the hillslope. To address road runoff from causing or accelerating sediment delivery from unstable areas, a measure was included which prevents the discharge of concentrated surface flow onto unstable features.

In order to address sediment delivery from unstable areas from non-road related sites, mitigation measures are included in the Guidelines for the Erosion Control Plans which prohibit land management activities which may accelerate movement of unstable areas. These measures include retention of <(fifty)> (SEVENTY FIVE) percent <(50%)> of HISTORIC <existing> basal area formed by tree species and the minimization of management activities on unstable areas. These measures were included to allow land use activities while providing protection to known unstable areas by minimizing direct hillslope disturbance on the unstable areas.

<u>Prevention of New Sediment Delivery Sites</u>

Another crucial component of the Guidelines for the Erosion Control Plans is to aid landowners and managers in the implementation of land management practices which prevent or significantly decrease the potential for the creation of new sediment delivery sources. As described earlier, the role that roads have on relative sediment delivery has been well documented. To provide clear guidance to land managers, Regional Water Board staff has required that road, landing and crossing construction utilize, at a minimum, the standards described in the Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994) (Handbook).

The Handbook was developed for the Mendocino County Resource Conservation District in cooperation with the California Department of Forestry and Fire Protection and the United States Department of Agriculture Soil Conservation Service. It includes sections on planning, design, construction, maintenance and closing of forest and ranch roads. The Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994) is a well written document and provides clear guidance to landowners and managers in developing a long term stable road network. This includes placing an emphasis on correcting and preventing sediment discharge into watercourses. The specific construction standards described in the Guidelines for the Erosion Control Plans are based on information contained in the Handbook. The Handbook provides further detail on appropriate construction, reconstruction, abandonment, and obliteration methods.

To achieve a long term stable road system, the strategy requires that a road plan be developed for each ownership. Roads are to be constructed, reconstructed, abandoned or obliterated based on the long term needs of the landowner or consortium of landowners. It is the intent of the Regional Water Board staff that the road system network be planned, designed and maintained to meet the needs of the landowner while preventing the delivery of sediment into watercourses. The long term road plan is an important component of both the Handbook and the Strategy. It is crucial that the long term road plan address the timing and feasibility of routine maintenance of the entire road system, including watercourse crossings.

<u>Reduction of Wet Weather Discharges</u>

The Guidelines for the Erosion Control Plans include conservation measures designed to prevent the delivery of sediment into watercourse during wet weather and wet soil conditions. There have been a number of published studies which document sediment delivery from roads during wet conditions. These include studies based on proximity of roads and landings to watercourses, depth and type of road surface material, and moisture content of road surface (Cafferata 1989, Burroughs, et. al., 1984, Burroughs and King 1989, Kochenderfer and Helvy 1987).

To prevent the controllable input of sediment from roads located adjacent to a watercourse, the Guidelines for the Erosion Control Plans require that all roads needed for land management activities within the Riparian Management Zone be surfaced with sufficient depth of competent rock to prevent road fines from being delivered to watercourses. An additional measure requires that sediment traps be installed at the outlet of all road drainage structures if less than one hundred feet (100') of undisturbed buffer exists between the outlet and the watercourse. It has been shown in a number of studies that a one hundred feet (100') buffer strip of well vegetated, relatively flat topography is capable of filtering out a relatively high percentage of sediment carried by surface flow (Moring 1982 and Lynch 1985). Sediment traps, such as straw bale or silt fence check dams, are required to decrease the volume of fine sediment transported by surface flow across filter strips that are less than one hundred feet (100') in width.

The Guidelines for the Erosion Control Plans do not allow the use of active watercourse channels for roads, landings or skid trails in order to prevent the placement of soil and debris directly into watercourses. This measure will also increase bank stability by prohibiting operations within the active channel. While this is an existing requirement of the Forest Practice Rules, exceptions to the Forest Practice Rules requirement that allow the use of instream facilities could be approved under a Timber Harvest Plan but would not be allowed under the Guidelines of the Erosion Control Plans for Redwood Creek Watershed.

A prohibition on the use of skid trails on slopes greater than forty percent (40%) within two hundred feet (200)' of a watercourse is also required under the Guidelines for the Erosion Control Plans. This measure is derived from information contained in the Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994) which relates width of buffer strip with slope of topography (as expressed in percent slope) to sediment filter capacities.

The Guidelines for the Erosion Control Plans also contains a management practice which prevents the use of roads, landings, skid trails or agricultural facilities when use of the facility causes the discharge of turbid water to flow into a watercourse in amounts which cause a visible increase in turbidity of the natural receiving water. This provision is based on an existing water quality objective of the Basin Plan which prevents land management activities from causing greater than twenty percent (20%) increase in turbidity above naturally occurring background levels. A twenty percent (20%) increase in turbidity is generally the level discernible by eye and can be observed without monitoring equipment. This management practice is included to aid landowners and managers during development and use of the road system and provide consistency with the Basin Plan.

To decrease potential for road fines to be discharged to watercourse during wet weather conditions, the Guidelines for the Erosion Control Plans requires that roads to be used for regular year-round use or use between October 15 and May 1 during the wet weather season be constructed, reconstructed or surfaced to comply with the standards of a permanent road. This provision is two-fold and requires adequate road surfacing and the installation of an adequate number and type of permanent road drainage (rather than relying on the installation of temporary structures such as waterbars). This will decrease the amount of soil disturbance caused by repeated disturbance of the road prism. Provisions are included to allow for use of heavy equipment on roads after October 15 under certain circumstances authorized by the National Marine Fisheries Service (NMFS). Such use should not result in significant sediment discharges to watercourses, as the NMFS is the lead agency for ensuring protection of species that have been listed on the Endangered Species Act, including coho salmon. Delivery of livestock feed on stable land is also allowable. An enforceable definition of a stable road surface is also included. This has been included to provide landowners and managers with a definition that is related to the potential of the road prism to concentrate runoff and deliver sediment to a watercourse.

A timing requirement related to the installation of drainage and/or collection and storage facilities on roads, landings, skid trails and agricultural facilities has been included which is based on site specific terrain and weather conditions. Rather than basing installation of drainage structures on a calendar date, the Guidelines for the Erosion Control Plans requires the installation of erosion control structures prior to the first rain that generates overland flow. This measure is based on a requirement of the existing Forest Practice Rules but has been expanded to include all facilities related to land management activities and applies throughout the year.

Because road construction and reconstruction operations usually involve substantial earth movement, these activities are generally restricted to those time periods when the likelihood of significant rain events are minimized. By prohibiting road and crossing construction and reconstruction from October 15 to May 1, substantial soil excavation will not occur when high intensity rain events are probable.

Removal and stabilization of temporary watercourse crossings and fill material by October 15 is required in the Guidelines for the Erosion Control Plans to decrease the potential for temporary fills and exposed soil along approaches to be delivered directly into watercourses during fall rain events. This measure is based on an existing regulation of the Forest Practice Rules which requires removal and stabilization of temporary crossings by November 15 unless approved in a Timber Harvest Plan. Given the likelihood of significant rain events before November 15, Regional Water Board staff have routinely recommended that temporary crossings be removed by October 15 during the review of Timber Harvest Plans in the North Coast Region. Specific requirements, including: 1) slope back watercourse crossing approaches to less than fifty percent (50%) side slopes and 2) stabilize watercourse crossing approaches from the lowest (most downslope) erosion control structure to the watercourse channel, were included to prevent failure of fill material into watercourses and the delivery of road fines into watercourses from surface erosion. These conservation measures are based on the Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994).

Activities in the Riparian Zone

To protect and restore the beneficial uses of water, a Riparian Management Zone is required when land management activities have the potential to discharge sediment into a watercourse. The widths of the Riparian Management Zones are based on the beneficial uses of water. The existing Forest Practice Rules, other conservation plans and the scientific literature all support the designation of a specific width of land adjacent to a watercourse in which land management activities are all developed and implemented with a focus on protecting water quality.

The Handbook for Forest and Ranch Roads (Weaver and Hagans, 1994) identifies buffer strips ranging from fifty feet (50') in width for areas with a zero percent (0%) side slope between road and watercourse, to one hundred and seventy feet (170') for thirty percent (30%) side slopes, up to three hundred and thirty feet (330') for seventy percent (70%) side slopes. The Forest Practice Rules base the minimum width on both the beneficial use of the water and the adjacent side slope. Protection zones for fish bearing watercourses, under the Forest Practice Rule classification system, range from seventy five feet (75') for slopes less than thirty percent (30%), to one hundred and fifty feet (150') for slopes greater than fifty percent (50%).

As described earlier in this section, there is a body of scientific literature which supports the assignment of one hundred foot (100') wide riparian management zones for the control of sediment carried by unchanneled water. There is additional scientific literature which indicates that sixty to ninety percent (60 to 90%) of instream large woody debris is recruited from within 15 meters (forty nine feet) (McDade, et al 1990). Other authors (Murphy and Kroski 1989; Johnson and Ryba 1992; Davies and Nelson 1994; Ledwith 1996) recommend that thirty meter (ninety eight foot) width protection zones should be provided to maintain adequate levels of future instream large woody debris.

Based on the existing literature and regulations, this strategy establishes a Riparian Management Zone of one hundred feet (100') be applied to all watercourses which directly support a beneficial use of water. The beneficial uses described in the Basin Plan for the Redwood Creek include but are not limited to domestic water supply (MUN), cold freshwater habitat (COLD), estuarine habitat (EST), migration of aquatic organisms (MIGR), spawning, reproduction and/or early development of fish (SPAWN), and rare, threatened, or endangered species of plants or animals (RARE).

A ONE HUNDRED <(fifty)> foot wide Riparian Management Zone will apply to all other watercourses (those that do not directly support beneficial uses of water) within the Redwood Creek watershed. While those watercourses which do not directly support beneficial uses of water tend to be located in headwater locations and in areas with relatively steep terrain, a ONE HUNDRED (100) <(fifty foot (50'))> wide riparian management zone will be applied due to the potential for watercourses to meter small amounts of fine sediment through the system during higher flows. A buffer zone will filter out sediment that could be transported downstream to watercourses where adverse impacts to fish and other aquatic species habitat may occur. It was Regional Water Board staff's judgment that the conservation measures contained in the Guidelines for the Erosion Control Plans coupled with the sediment filter capabilities of the undisturbed (or stabilized) buffer strip will result in a minimal amount of fine sediment delivery into the watercourse. The metering abilities of the watercourse will further prevent the significant discharge of fine sediment into watercourses which directly support beneficial uses of water.

Rather than include a blanket prescription which prevents the use of heavy equipment within the Riparian Management Zone, the Redwood Creek watershed erosion control plan includes a provision which requires that the sediment filtering abilities of the Riparian Management Zone are protected or enhanced during and following land management. To this end, the Redwood Creek watershed erosion control plan states that it is the goal to maintain one hundred percent (100%) of surface vegetation and/or duff within the zone, or, if disturbance to the vegetative layer does occur during land management activities then all disturbed soil will be stabilized to achieve at least 90 percent coverage. This will provide roughly equivalent sediment filtering capacity when compared to an undisturbed zone. This measure is based on an existing provision of the Forest Practice Rules.

To ensure that adequate vegetation remains along watercourse banks during commercial land management activities, the Guidelines for the Erosion Control Plans include a twenty-five foot (25') strip within the Riparian Management zone where commercial land management activities, including grazing, are restricted. This measure is included to ensure that trees, shrubs, grasses, and forbs are retained and have the ability to grow along the watercourse banks to promote bank stability. Information contained in the 1993 FEMAT report relates root strength adjacent to the watercourses with a riparian zone width based on the height of a site-potential tree. The FEMAT information indicates that root strength is increased when a retention zone width of one third of the site potential tree is maintained adjacent to the watercourse. The measure contained in Guidelines for the Erosion Control Plans is based on the inherent instability of streambank zones in the

Redwood Creek watershed, and the effectiveness of root strength, shrubs, forbs, and grasses to stabilize the soil adjacent to watercourses, as well as the effectiveness of evapotranspiration by trees in removing moisture from soils to decrease the potential for landsliding. Studies by Professor Peter Bosscher of the University of Wisconsin-Madison (1996) have documented the effectiveness of the root reinforcement of vegetation in holding soil particles together. His studies also showed the effectiveness of evapotranspiration of the trees and root systems at removing moisture from the soil. The higher or more prolonged the periods of elevated moisture stress in a slope, the higher will be the creep rates and the greater the danger of landslides. And the relationship of the interception of rainfall by the tree canopy was also documented, which reduces the erosive potential of rainfall.

Channel process and channel morphology in Redwood Creek tributaries are strongly influenced by large organic debris (Pitlick, 1982). Because large woody debris plays such a crucial role in the formation of instream fish habitat and provides storage, sorting and metering of instream sediments, provisions are included in the Redwood Creek watershed erosion control plan to maintain current instream and near stream large woody debris as well as to provide for recruitment of future instream large woody debris by requiring retention of adequate sizes and numbers of near stream trees.

To prevent the removal of existing instream large woody debris and woody debris available to the watercourse in the short term, the Redwood Creek watershed erosion control plan states that no removal of downed woody debris within the watercourse or from the Riparian Management Zone shall not occur unless a safety hazard exists. The lack of existing instream large woody debris in watercourses has been identified in the Redwood Creek watershed (Klein et al.1997).

To increase potential for future large woody debris to enter a watercourse, a provision is included in the Redwood Creek watershed erosion control plan which prohibits the removal of trees from unstable areas that have direct access to watercourses. This measures applies to all watercourses within the watershed. As described earlier, large woody debris serves a number of purposes in the instream environment, including habitat formation and sediment metering. As such, the presence of large woody debris is important in watercourses which support beneficial uses of water as well as those which have the ability of carrying sediment to watercourses which support beneficial uses.

To ensure that land management activities do not result in the removal of near stream trees needed to supply an adequate volume of future large woody debris, specific tree retention standards are included in the Redwood Creek watershed erosion control plan. The measure calls for the permanent retention of five conifers greater than thirty two inches (32") in diameter at breast height (DBH) per one hundred linear feet (100') of watercourse. The average of at least three of the retained trees is to be at least forty inches (40") DBH. If these standards can not be met the five largest trees per one hundred feet (100') of watercourse shall be permanently retained. This measure is based on recommendations generated by the California Department of Fish and Game during timber harvest plan review and development for watercourses within the North Coast Region.

ECONOMIC CONSIDERATIONS

The proposed Water Quality Attainment Strategy (WQAS) for the Redwood Creek watershed specifies a Total Maximum Daily Load (TMDL) of sediment for the watershed. The WQAS also specifies actions needed to implement the TMDL and monitor its effectiveness. One component of the WQAS is an estimate of the cost impacts, particularly the costs to be borne by private landowners within the watershed.

The most significant cost of implementing the WQAS is the cost of improving unpaved roads in the watershed. Inadequately constructed roadways suffer significantly greater rates of erosion during more severe storm events than properly constructed roadways. The attainment strategy has the goal of improving all the roads over a period of 12 years.

The WQAS also proposes other changes in land use practices to reduce erosion. The most important of these is construction of fencing to restrict access by grazing livestock to erosion-prone stream banks, especially where natural barriers are lacking. Although most of the sediment loading associated with ranching activities arises from the use of roads, some additional sedimentation results from unrestricted cattle access to water at erosion-prone creek sites.

The WQAS also proposes specific logging practices, although these are already required under current provisions of the Forest Practices Guidelines. These include restrictions on timber harvesting along creeks and secondary watercourses, and leaving downed large woody debris in watercourse channels. Since portions of these practices are already mandated by harvesting regulations, there will be no additional cost as a result of those portions of the WQAS.

Detail: Cost of Improving Logging Roads

The goal of this economic analysis is to determine the additional costs to landowners as a result of the WQAS. A primary source of soil erosion in the watershed is unsurfaced logging roads and logging landings. Since all of the logging in the Redwood Creek watershed occurs on private land, these landowners will bear the largest share of the cost of the WQAS.

However, since some of the WQAS's requirements are already included in requirements administered by the California Department of Forestry, not all of the WQAS will alter the existing land-use practices for these landowners. In addition, some currently scheduled improvements are already included in existing agreements between private landowners and the Redwood National Park, and in some cases State or Federal funding for some road improvements have already been arranged. The cost of road improvements included under these agreements will not change as a result of the WQAS.

There are currently approximately 1,340 miles of unsurfaced roadways within the 178,000 acre Redwood Creek watershed. About 85% of the roads occur on about 60% of the privately-owned harvestable timberlands, located principally in the southern two-thirds of the watershed. The cost estimates were based on a sample survey of road conditions on these 107,000 acres[confirm that these numbers are the same as we cite in our problem statement]. The detailed inventory of this private road system, construction of improvements and decommissioning, removal of a small portion of these roads, and annual maintenance of the remaining roads, is estimated to require 8 to 12 years to complete. Table 4 shows the costs of the improvements needed on the 1,340 miles of road, and the approximate span of years that the costs will be incurred.

The total miles in each category were spread over the number of years indicated for that category, and multiplied by the cost per mile for that road category. Annual maintenance costs of $100 to $500 per mile, depending on topography, were added annually as appropriate for each category that is affected by the WQAS. The amounts were summed for each year, and discounted at 5%. Since the annual costs were not inflated, and since the long-term inflation rate is about 3%, the 5% real discount rate is equivalent to an annual discount rate of 8%.

The necessary improvements to the roadway system would have a total construction cost of $17.9 million. However, since the improvements will largely occur over a period of 8 to 12 years (depending on road category), and taking the cost of capital into account, the total present-value cost of the road improvements is about $14.1 million. For the roughly 107,000 acres of private forest land, where the bulk of these costs will be incurred, the annualized cost for the first 12 years is about $14.20 per acre, per year.

Since much of the cost of these road improvements is the cost of metal culverts that have a life-span of about 25 years, the maintenance costs were calculated over a project life-span of 25 years. After the roads are constructed to higher standards, the annual maintenance costs were calculated at $500 per mile (with a small portion of the system mileage calculated at $100 per year). The total roadway system maintenance costs are calculated to average about $303,000 per year, in present value, or about $2.85 per acre per year over the 25-year discount period.

No attempt was made to calculate separately the maintenance costs for each category in the share of roadways within that category that will be upgraded to "permanent" or year-round roads. Current forest practices guidelines specify that such roads should be "rocked as necessary", although in many instances six inches of rock are an appropriate amount. Thus, there was no way to project what an individual landowner would determine was needed. Instead, broad cost estimates were incorporated.

Detail: Cost of Fencing for Cattle

Cattle ranching in the watershed results in two primary types of soil erosion: erosion from roads used for cattle access, and erosion from cattle access to stream banks. The cost of controlling erosion from access roads has been included with the estimate for logging roads. Stream bank erosion, though, is estimated by RWQCB staff to result in about 12% of the current sediment loading. It is further estimated that control of about 35% of this amount can be attained by controlling cattle grazing.

For this reason, the WQAS contains a component that proposes that cattle be restricted from the most sensitive, erosion-prone, creeksides, and Riparian Management Zones (RMZs). The RMZ widths, as measured from the active channel or bank full stage, whichever is wider, are: 1) 100 feet each side of the watercourse for watercourses that directly support beneficial uses of water (Class I and II), and 2) 50 feet each side of the watercourse for all other watercourses (Class III). Fencing is one alternative. The proposal would generally necessitate that cattle be actively restrained from entering the streams when:

- the cattle are attracted by running water in the creek or tributary (usually nearly year-round)
- there is a sensitive stream-side that is not graveled, and
- there is no natural barrier to prevent access of cattle to the stream-site. Natural barriers include steep cliffs and thick berry-patches.

The actual number of miles of streams that might be affected is difficult to calculate. However, an approximate number may be estimated as follows:

Item	Value	Remarks
Total private acreage, within the watershed, that may have some cattle grazing.	21,350 acres (33.4 sq. miles)	Total watershed above Orick is 278 square miles. 60% of total watershed is private, and 20% of this area may be grazed. 60% x 20% = 12% 12% x 278 = 33.4 sq. miles.
Total length of waterways within grazing area.	234 miles	In coastal mountains, 7 miles of waterways per sq. mi. of watershed (Greg Bundros, Redwood National Park).
Total length of waterways potentially susceptible to cattle-induced erosion.	93 miles	39% of waterways are Class II, which are most likely to be found in grazing areas. Other waterways are Class I (3%) and Class III (58%). *

Total length of erosion-prone riparian banks in grazing areas.	186 miles	Both banks along Class II waterways.
Total length of fencing required over a 15-year period.	48 miles	Assume a maximum of 1/4 of total length of banks requires protective fencing, to be constructed at 4 miles/year.
Present Value of fence construction cost, for 25 years.	$299,000	Fencing construction cost of $7,000 per mile, at 4 miles per year. After 12 years, 1/4 of the aged fence requires new construction annually.
Present Value of fence maintenance cost for 25 years.	$157,400	Fence maintenance cost of $500 per mile per year, beginning 5 years after construction, maximum of 48 miles to be maintained.

* Class I streams contain domestic water supplies, and include historically fish-bearing streams. Class III streams do not have aquatic life present, but show evidence of being capable of sediment transport. Class II streams have fish always or seasonally present within 1000 ft; and/or contain aquatic habitat for non-fish aquatic species.

Although fencing of stream banks is not specifically required, in instances where other erosion-control measures are deemed inadequate to attain the desired reduction, fencing may become necessary. For the purpose of providing a cost of fencing for the WQAS, it was estimated that the total distance of 5-strand steel-post fencing to be constructed is 48 miles.

The total of 48 miles of fencing is to be constructed at a rate of 4 miles each year for 12 years, and re-constructed at a rate of 1 mile per year for the remaining 13 years. At a cost of $7,000 per mile for materials and labor, the current annual construction cost would be $0.95 per acre per year, for a period of 25 years. The annual maintenance costs of $500 per mile begin in year 6, and reach a maximum in year 17. The combined 25-year construction and maintenance costs for the maximum of 48 miles (61 miles total constructed fence) is discounted to $456,500. The discounted average annual equivalent expenditure for fencing is about $30,900. Averaged over 21,350 acres, this is equivalent to a discounted average annual cost of $1.44 per acre.

Detail: Cost of Riparian Management Zone

The proposed WQAS contains provisions to reduce the impact from soil erosion from near-stream timber harvest. Some protection against soil erosion is currently provided by Timber Harvest Plans (THPs) that are approved pursuant to the Forest Practice Rules (FPRs). Under the THPs, specific waterways are protected by establishing Watercourse and Lake Protection Zones (WLPZs). These are analogous, but not identical, to the Riparian Management Zones (RMZs) specified in the WQAS.

The THPs commonly specify either harvest practices, timber protection or shade canopy in a strip of land up to 150 feet from the stream center, usually in increments of 25 feet. The waterways are categorized as being either Class I, Class II, or Class III waterways. The minimum requirements also vary according to soil stability and slope. In most instances, the proposed RMZs specify similar setback distances as contained in the FPRs. This economic analysis compares the costs related to the proposed WQAS with the costs under the existing FPRs.

The most significant requirement under the proposed Implementation Plan for RMZs would require no land management within 25 feet of any watercourse, and within unstable areas. FPR 916.5 "G", "H" and "I", specify minimum requirements for understory and overstory canopy retention in the first 25 foot zone. The difference, in terms of timber harvest allowed, is that the proposed WQAS could result in roughly a 50 percent increased retention of timber in the 25 foot zone, and a greater percentage retention in other unstable areas.

An increase in the number of conifers required to be retained results in a potential loss of revenue for the owners of the timber property. This loss of revenue occurs only in selected areas, in selected zones, and over a period of several decades. A complete analysis would require an on-ground stand density survey for the entire privately-owned timberland in the upper Redwood Creek watershed. An estimate of the potential revenue loss has been made using available data from the Redwood Creek watershed, some coastal forest harvest data, and some additional data from similar areas.

Several simplifying assumptions were necessary to estimate the lost revenue. The chief assumption is that the owners of the timberland are a homogenous group. In reality, over 90% of the timberland is owned by large landowners, primarily involved in the growth and harvest of forest products. However, about 10% of the land in the upper Redwood Creek watershed is owned by resident landowners, who may not be interested in harvesting the timber on their land. Many of these small holdings serve as residential homesites, and tend to be adjacent to Class I or Class II watercourses. No attempt was made to determine the economic impact of the proposed WQAS upon specific residents or landowners.

The Redwood Creek watershed drains a total area (above Orick) of about 278 square miles, or 182,000 acres. Within this area, harvestable timber is found on about 60% of the area, or 170 square miles. The coastal mountains contain about 7 miles of waterway per square mile of watershed, resulting in about 1190 miles of waterways within the upper 60% of the Redwood Creek watershed, equivalent to about 91 acres per mile of waterway. As stated previously in a previous section of the economic analysis, the following percentages are used to allocate the length of waterways by class: Class I, 3%; Class II, 39%; Class III, 58%. The waterways affected by timber retention provisions of the WQAS are Class I and Class II.

It is assumed that the average age of the redwood timber stands harvested in this area is about 60 years. Additional assumptions used to simplify the calculations include:

- 30% of 25-foot riparian zone along Class I and Class II waterways contains harvestable timber under FPR, and some small additional area has unstable slopes
- a 60-year-old stand (define) of redwood, with a site index of 180 (define), contains 106 MBF (thousand board feet)/acre.
- the current Board of Equalization value for tractor-logged young growth redwood in Humboldt and Del Norte counties, currently about $580 / MBF, will not be susceptible to significant inflation in the next 25 years.

Item	Value	Remarks
Total private acreage, in the watershed containing timber	170 sq. mi	Total watershed above Orick is 278 square miles. 60% of total watershed is timberland 60% x 278 = 170 sq. miles.
Total length of waterways within timberland	1190 miles	In coastal mountains, 7 miles of waterways per sq. mi. of watershed (Greg Bundros, Redwood Nat'l Park) 7 mi/sq.mi (x) 170 sq.mi. = 1190 sq. mi.
Total length of waterways that generally contain flowing water.	500 miles	42% of watercourses are Class I and Class II, most likely to be affected by the WQAS 42% x 1190 miles = 500 miles
Total length of affected waterways with harvestable timber within twenty five feet of the waterway or in unstable	150 miles	30% of Class I and Class II waterways. 30% (x) 500 miles = 150 miles

areas within the riparian management zone.		
Total number of acres included in the 25-foot riparian zone along both banks of the affected waterways.	900 acres	50 feet (x) 1 mile = 6 acres. 6 ac./mi. (x) 150 miles = 900 acres
Value of typical stand of good timber (60 yrs, SI=180)	$61,480	106 MBF/acre (x) $580 / MBF = $61,480 / acre (quantity from DOF, Bull. 106; value from BOE Timber Harvest Report)
Value of entire acreage of standing timber, immediate harvest.	$55.31 Mil.	Assume entire stand of 900 acres harvested. 900 acres (x) $61,580/acre = $55.31 million
Present Value of entire acreage of timber harvested over a period of 25 years.	$32.74 Mil.	Assume the timber is harvested at 36 acres per year, for 25 years. Price remains constant, and discount rate is at 5%.
Present Value of reduced timber harvest, at three different levels of reduction: 30% reduction 50% reduction 70% reduction	$9.82 Mil $16.37 Mil $22.92 Mil	Assume existing stand is fixed in size and price, with uniform reduction over 25-year period, discounted at 5%.

The calculations above involve several substantial simplifications of a very complex situation. For example, the present value calculations assume that landowners harvest their timber uniformly over a period of 25 years. Landowners would tend to harvest in this way if the rate of growth in the volume of timber on their property is approximately equal to the discount rate.

If ownership patterns in the watershed are fairly uniform – i.e., individual landholdings don't deviate significantly from the assumption of 7 miles of watercourse per square mile, and the relative shares of Class I, II and III watercourses – it is also possible to compare the revenue loss from timber retention with the estimated cost of road repair on the same land. The revenue loss can be spread across the 107,000 acres of timberland, over the 25 year period. The calculations for three levels of reduced revenue are equivalent to the following per-acre costs:

Reduction in timber harvest	<u>total</u> lost revenue (discounted)	<u>25-year average annual revenue loss per acre</u>
30%	$9.82 mil.	$3.67
50%	$16.37 mil	$6.12
70%	$22.92 mil	$8.57

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GLOSSARY

Aggradation	To fill and raise the elevation of the stream channel by deposition of sediment.
Agricultural facility	Any building, corral, pen, pasture, field, trail, or other feature on the landscape which is attributable to or associated with agricultural operations.
Anadromous	Refers to aquatic species which migrate up rivers from the sea to breed in fresh water.
Areas of instability	Locations on the landscape where land forms are present which have the ability to discharge sediment to a watercourse.
Baseline data	Data derived from field based monitoring or inventories used to characterize existing conditions and used to establish a database for planning or future comparisons.
Beneficial Use	Uses of waters of the state that may be protected against quality degradation including, but not limited to, domestic, municipal, agricultural and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and the preservation and enhancement of fish, wildlife and other aquatic resources or preserves.
Class I	Watercourses which contain domestic water supplies, including springs, on site and/or within 100 feet downstream of the operation area and/or have fish always or seasonally present onsite, including habitat to sustain fish migration and spawning. Class I streams include historically fish-bearing streams.
Class II	Watercourses which have fish always or seasonally present offsite within 1000 feet downstream; and/or contain aquatic habitat for non-fish aquatic species. Class II waters do not include Class III waters that are directly tributary to Class I waters.
Class III	Watercourses which do not have aquatic life present, but show evidence of being capable of sediment transport to Class I and II waters under normal high flow conditions during and after completion of land management activities.
Class IV	Human-made watercourses, which usually supply downstream established domestic, agricultural, hydroelectric supply or other beneficial uses.
Controllable source	Any source of sediment with the potential to enter a water of the State which is caused by human activity and will respond to mitigation, restoration, or altered land management.
Debris torrents	Long stretches of bare, generally unstable stream channel banks scoured and eroded by the extremely rapid movement of water-ladened debris, commonly caused by debris sliding or road stream crossing failure in the upper part of a drainage during a high intensity storm.

Deep seated landslide Landslides involving deep regolith, weathered rock, and/or bedrock, as well as surficial soil. Deep seated landslides commonly include large (acres to hundreds of acres) slope features and are associated with geologic materials and structures.

Drainage structure A structure or facility constructed to control road runoff. These structures include but are not limited to fords, inside ditches, water bars, outsloping, rolling dips, culverts or ditch drains.

Flood event Flood frequency analysis defines the event which can be expected once every "Y" years, on the average. This does not imply that a "Y-year event" will occur regularly every "Y" years. Return periods, as well as flood magnitudes, are subject to analysis. For example, there is a two percent chance that a 50-year event will occur I any one year.

Flooding The overflowing of water onto land that is normally dry.

Fry A young juvenile salmon after it has absorbed its egg sac and emerged from the redd.

Headwater swale The swale or dip in the natural topography that is upslope from a stream, at its headwater. There may or may not be evidence of overland or surface flow of water in the headwater swale.

Interstices The space between particles (e.g. space between sand grains).

Inner gorge A geomorphic feature formed by coalescing scars originating from mass wasting and erosional process caused by active stream erosion. The feature is identified as that area of stream bank situated immediately adjacent to the stream, having a slope generally over 65% and being situated below the first break in slope above the channel.

Inside ditch The ditch on the inside of the road, usually at the foot of the cutbank.

Landslide Any mass movement process characterized by downslope transport of soil and rock, under gravitational stress by sliding over a discrete failure surface-- or the resultant landform.

Large woody debris A piece of woody material having a diameter greater than 30 cm (12 inches) and a length greater than 2 m (6 feet) that is located in a position where it may enter the watercourse channel.

Mass wasting Downslope movement of soil mass under force of gravity-- often used synonymously with "landslide." Common types if mass soil movement include rock falls, soil creep, slumps, earthflows, debris avalanches, debris slides and debris torrents.

Numeric targets A numerical expression of the desired instream environment. For each stressor or pollutant addressed in the problem statement of the Strategy , a numeric target is developed based on the numeric or narrative State water quality standards which are needed to recovered the impaired beneficial use.

Permanent drainage structure — A road drainage structure designed and constructed to remain in place following active land management activities while allowing year round access on a road.

Planning Watershed — The uniform designation and boundaries of sub watersheds within a larger watershed. These Watersheds are described by the California Department of Forestry as Cal Water Watersheds.

Redd — A gravel nest or depression in the stream substrate formed by a female salmonid in which eggs are laid, fertilized and incubated.

Sediment — Fragmented material that originates from weathering of rocks and decomposed organic material that is transported by, suspended in, and eventually deposited by water or air.

Sediment budget — An accounting of the sources, movement, storage and deposition of sediment produced by a variety of erosional processes, from its origin to its exit from a watershed.

Sediment delivery — Material (usually referring to sediment) which is delivered to a watercourse channel by wind, water or direct placement.

Sediment discharge — The mass or volume of sediment passing a point in the stream in a unit of time.

Sediment erosion — The group of processes whereby sediment (earthen or rock material) is loosened, dissolved and removed from the landscape surface. It includes weathering, solubilization and transportation.

Sediment source — The physical location on the landscape where earthen material resides which has or may have the ability to discharge into a watercourse.

Sediment yield — The sediment yield consists of dissolved, suspended and bed loads of a watercouse channel through a given cross-section in a given period of time.

Shallow seated landslide — A landslide produced by the failure of the soil mantle (typically to a depth of one or two meters, sometimes includes some weathered bedrock), on a steep slope. It includes debris slides, soil slips and failure of road cut-slopes and sidecast. The debris moves quickly (commonly breaking up and developing into a debris flow) leaving an elongated, concave scar.

Skid trail — Constructed trails or established paths used by tractors or other vehicles for skidding logs. Also known as tractor roads.

Smolt — A young salmon at the stage at which it migrates from fresh water to the sea.

Spittler Crossing	A temporary watercourse crossing, where logs are bundled together and installed in the watercourse to minimize the need forsoil fill material. A culvert is installed with the logs, where surface flow is expected. A 6 inch or greater layer of straw is placed on top of the logs, and topped with a soil cap to provide a running surface. Upon completion of use, and prior to winter period, the soil, logs, and culvert are removed.
Steep slope	A hillslope, generally greater than 50% that leads without a significant break in slope to a watercourse. A significant break in slope is one that is wide enough to allow the deposition of sediment carried by runoff prior to reaching the downslope watercourse.
Stream	See watercourse.
Stream class	The classification of waters of the state, based on beneficial uses, as required by the Department of Forestry in Timber Harvest Plan development. See definitions for Class I, Class II, Class III, and Class IV for more specific definitions.
Stream order	The designation (1,2,3, etc.) of the relative position of stream segments in the drainage watershed network. For example, a first order stream is the smallest, unbranched, perennial tributary which terminates at the upper point. A second order stream is formed when two first order streams join. Etc.
Sub watershed	A subset or division of a watershed into smaller hydrologically meaningful Watersheds. For example, the North Fork Redwood Creek is a sub watershed of the larger Redwood Creek watershed.
Swale	A channel-like linear depression or low spot on a hillslope which rarely carries runoff except during extreme rainfall events. Some swales may no longer carry surface flow under the present climatic conditions.
Thalweg	The deepest part of a stream channel at any given cross section.
Thalweg profile	Change in elevation of the thalweg as surveyed in an upstream-downstream direction against a fixed elevation.
Unstable areas	Characterized by slide areas, gullies, eroding stream banks, or unstable soils. Slide areas include shallow and deep seated landslides, debris flows, debris slides, debris torrents, earthflows and inner gorges and hummocky ground. Unstable soils include unconsolidated, non-cohesive soils and colluvial debris.
Watercourse	Any well-defined channel with a distinguishable bed and bank showing evidence of having contained flowing water indicated by deposit of rock, sand, gravel, or soil.
Waters of the state	Any surface water or groundwater, including saline water, within the boundaries of the state.

Watershed — Total land area draining to any point in a watercourse, as measured on a map, aerial photo or other horizontal plane. Also called a basin, drainage area, or catchment area.

Water quality objective — Limits or level of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area..

Water quality standard — Consist of the beneficial uses of water and the water quality objectives as described in the Water Quality Control Plan for the North Coast Region.